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Technical Note

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By Bingham Y.K. Pan and Brian Swaidan

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RECYCLING OF HYDROBLASTING WASTEWATER - FINAL FEASIBILITY REPORT

ABSTRACT The objective of this project undertaken by the Naval Civil Engineering Laboratory (NCEL) is to develop a recycling technology for reducing the volume of boiler hydroblasting wastewater at Naval Shipyards by up to 90 percent. Steam boiler tubes of a Navy ship undergoing regular overhaul are cleaned twice by hydroblasting. The first washing is performed before ship overhaul and the second washing after ship overhaul. The initial feasibility study, completed in FY88, involved bench scale work at NCEL and pilot scale tests at Long Beach (LBNSY) and Norfolk Naval Shipyards (NNSY). Full scale field tests were conducted at NNSY in FY89. The wastewater recycling process consisted of five steps: collecting, settling, filtering, reconditioning, and reusing. All five steps were successfully demonstrated in the three series of field tests. These tests were assisted by and coordinated with NNSY and Naval Ship Systems Engineering Station (NAVSSES). The results show that the hydroblasting wastewater could be recycled nine times to achieve 90 percent reduction without any adverse effect. The recycling unit is to be put alongside an existing hydroblast (waterjet) unit. The same safety precautions for hydroblasting operations are applicable to and should be observed for recycling operations. A 90 percent reduction represents approximately $8 million/year savings on wastewater disposal costs. More significant economic benefit can be realized if the recycling technology is adopted for boiler tube cleaning done at Navy activities outside Naval Shipyards.

NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043-5003

METRIC CONVERSION FACTORS

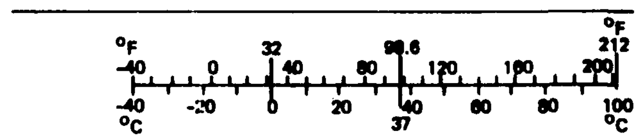
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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13. ABSTRACT *(Maximum 200 words)*

The objective of this project undertaken by the Naval Civil Engineering Laboratory (NCEL) is to develop a recycling technology for reducing the volume of boiler hydroblasting wastewater at Naval Shipyards by up to 90 percent. Steam boiler tubes of a Navy ship undergoing regular overhaul are cleaned twice by hydroblasting. The first washing is performed before ship overhaul and the second washing after ship overhaul. The initial feasibility study, completed in FY88, involved bench scale work at NCEL and pilot scale tests at Long Beach (LBNSY) and Norfolk Naval Shipyards (NNSY). Full scale field tests were conducted at NNSY in FY89. The wastewater recycling process consisted of five steps: collecting, settling, filtering, reconditioning, and reusing. All five steps were successfully demonstrated in the three series of field tests. These tests were assisted by and coordinated with NNSY and Naval Ship Systems Engineering Station (NAVSSES). The results show that the hydroblasting wastewater could be recycled nine times to achieve 90 percent reduction without any adverse effect. The recycling unit is to be put alongside an existing hydroblast (waterjet) unit. The same safety precautions for hydroblasting operations are applicable to and should be observed for recycling operations. A 90 percent reduction represents approximately $8 million/year savings on wastewater disposal costs. More significant economic benefit can be realized if the recycling technology is adopted for boiler tube cleaning done at Navy activities outside Naval Shipyards.

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INTRODUCTION

The Naval Civil Engineering Laboratory (NCEL) has been tasked by the Naval Facilities Engineering Command (NAVFAC) to investigate technology to reduce the volume of hydroblasting wastewater at Naval Shipyards. Hydroblasting is a high pressure water jetting method to remove the soft deposits on boiler tubes and other parts on the water side of the boiler. Sodium nitrite, a corrosion inhibitor, is added to potable water to make the feed solution.

The past operating procedure for hydroblasting was to use the feed solution for one cleaning pass and then mix this wastewater with other bilge wastes in the ship. Latest survey for 1987-1988 shows that Naval Shipyards generate about three million gallons of hydroblasting wastewater per year. Before NCEL started research and development work this wastewater was combined with other bilge wastes; these combined wastes resist available treatment. The contractor's charge for hauling and treatment is about to $3.25 per gallon.

The current project is a second year effort and is a final feasibility study to determine the recycling of wastewater. Reference 1 details the previous FY88 effort on the initial feasibility. The objectives of this fiscal year's effort are: (1) To conduct field tests of the complete recycling process; (2) To achieve 90 percent reduction of wastewater without any damage to the existing hydroblast unit; and (3) To clean the boiler tubes using the recycling process and pass standard inspection for the cleaned boiler.

TECHNICAL APPROACH

Field Test Layout

The recycling process consisted of wastewater collecting, settling, filtering, reconditioning, and reusing. Figure 1 shows the field tests layout. The bilge pump collected the hydroblasting wastewater separately and sent it to the settling tank. After settling and filtering, the wastewater was checked with chemical analysis and/or Hach instrumentation to determine the nitrite concentration. If necessary, the wastewater was reconditioned by the addition of sodium nitrite to bring up the nitrite to the required level. Then the treated wastewater was pumped back to the hydroblast unit for reuse.

The major problem with use of recycled wastewater is its suspended solids content, which can cause damage to the high pressure feed pump, lance orifices, and the boiler tubes. The first year's tests showed clearly the inadequacy of relying solely on small capacity filters without first using settling tanks for separation of the solids from the wastewater stream. Those results showed that for a first washing

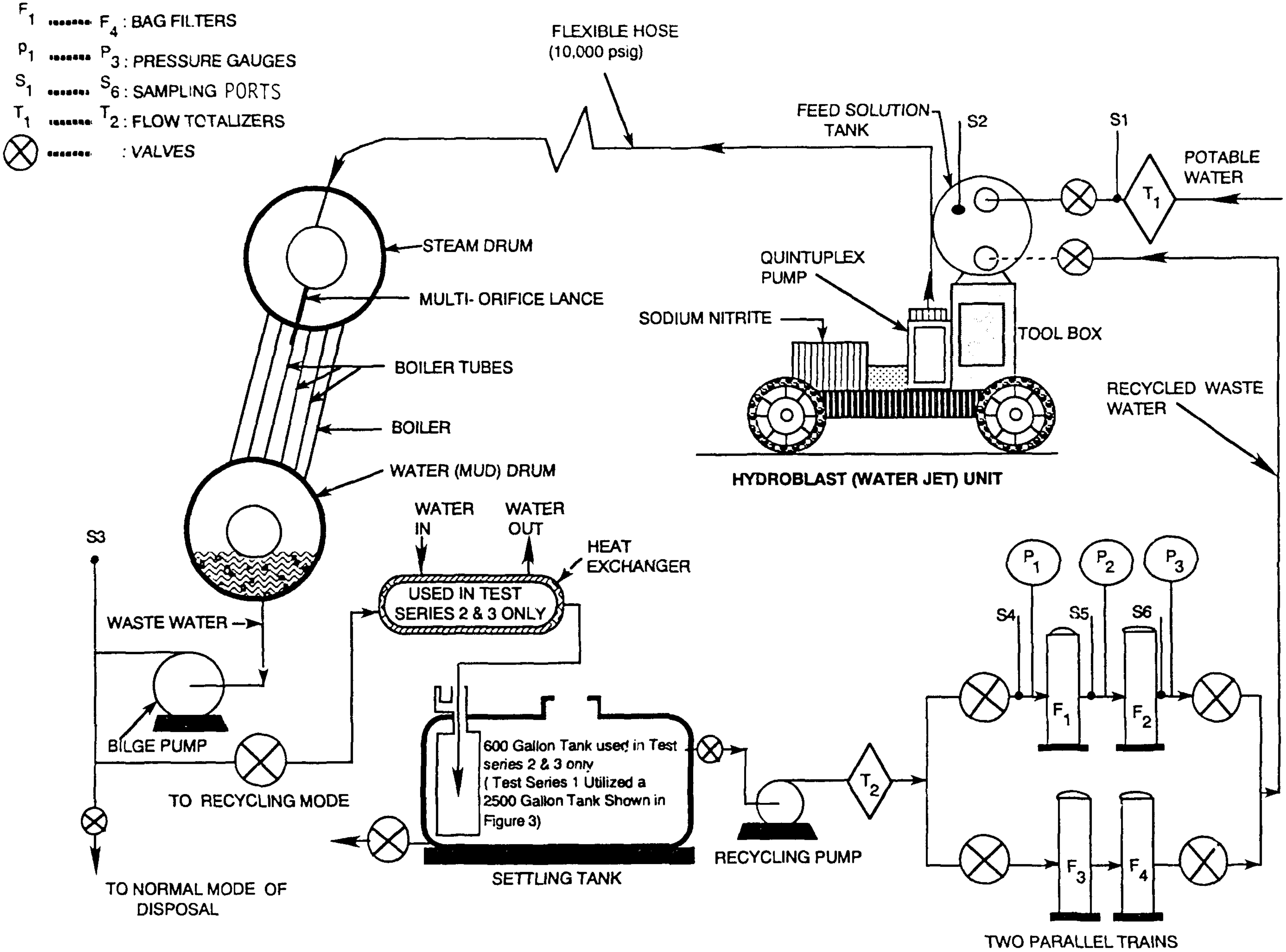

Figure 1. Layout of recycling process of hydroblasting wastewater.

wastewater and a 5-inch diameter by 7-inch long cloth filter, only 300 gallons can be filtered before a filter change was necessary. Therefore, a separation method was required to remove a substantial amount of suspended solids from the wastewater before filtration becomes a viable option. A settling tank of 2500-gallon capacity was added for the field tests. Also, the filter unit and filter arrangement were upgraded. Dual filter trains were set up with an easy valving arrangement that allowed the switch from one train to another. Each filter train consisted of a minimum of two filters in series and each filter has six times the surface area used in the pilot scale tests in FY88.

Two flow totalizers, T_1 and T_2, were used to measure the total amount of water necessary to clean a boiler. One totalizer measured the amount of freshwater feed and the other measured the recycled wastewater. At the conclusion of the first series of tests, only 7,950 gallons were required for that particular boiler cleaning. Therefore, in the second and third series of tests, a smaller settling tank of 600-gallon capacity was fabricated and used.

Selection of Test Site

Norfolk Naval Shipyard (NNSY) was selected for all three series of field tests. NNSY was highly cooperative in the recycling effort. Also, NNSY implemented a procedure by which the hydroblasting wastewater was collected separately from other bilge waste streams and pumped out to a tank car for disposal. This procedure made it very simple to divert the wastewater to our settling tank for testing.

Selection of Boiler

The boiler selection for our test was dictated by the availability and scheduling of the ship for the hydroblasting operations. The USS Dahlgren was the ship available, and its hydroblasting time was in accordance with NCEL's schedule. This ship has four boilers. Our field tests were done with two of the four boilers. The first and second series using Boiler 1A were conducted in April and June 1989. The third series using Boiler 2B was conducted in June 1989. The time between April and June allowed us to implement improvements based on the results of the first series of experiments.

TESTS AND DISCUSSIONS

The three tests conducted were first and second washings of boiler 1A and first washing of boiler 2B for the USS DAHLGREN - DDG 43. Table 1 is a summary of the field test conditions and results for each of the three tests. The field tests were executed by the NCEL team consisting of two engineers and two technicians. NNSY shop 41 hydroblast crew provided outstanding on-site assistance. NNSY chemical laboratory made many quick analyses. Naval Ship Systems Engineering Station (NAVSSES) sent a boiler inspector to examine the tube cleaning results and an engineer to assist and witness the test procedures. In addition, a

Table 1

FIELD TESTS CONDITIONS SUMMARY

Test Series	Date	Type Washing	WW Collected For Recycling (gal)	Recycles To Finish Boiler Cleaning	% WW Reduction Based on of Recycles
First	25-27 April 1989	1st to Boiler 1A	1,500	3	75
Second	21-23 June 1989	2nd to Boiler 1A	500	9	90
Third	24-27 June 1989	1st to Boiler 2B	500	12	92

Test Series	Fresh Feed Start (gal)	Total Water Used (gal)	Settling Tank Size (gal)	Use of Heat Exchanger
First	2,600	7,950	2,500	No
Second	2,100	8,650	600	Yes
Third	800	10,000	600	Yes

Remarks

1. The Uss Dahlgren has four boilers, 1 & 2 A, 1 & 2 B
2. Total Water Used, gallons

First series : 4,950 recycled, 2,600 start feed, & 400 make-up
Second series: 5,850 recycled, 2,100 start feed, & 700 make-up
Third series : 7,800 recycled, 800 start feed, & 1,400 make-up

representative from the Weatherford Company, which manufactured the hydroblast unit, watched for any potentially adverse effects during the first 10 hours test.

FIELD TEST PROCEDURES

1. Instruct hydroblast crew and on-site personnel of the valve arrangement for the recycling and normal modes of operation.

2. Ensure that the settling tank is clean and obtain sample of any residue.

3. Allow the hydroblast operations, using fresh feed solution, to proceed for the first half hour. Divert the first 100 gallons of wastewater to the normal mode of disposal and the rest to our settling tank. This half hour operation was intended to flush any residue in the water lines and to attain steady state condition.

4. Commence the charge-up of the settling tank.

5. Obtain a set of samples from sample ports S1, S2, and S3 and promptly deliver to the NNSY chemical laboratory or keep in an icebox until ready for pick-up. Samples from each port consist of three bottles. Two bottles containing a few drops of either sulfuric or nitric acid are for the preservation of oil and grease or metals respectively. The third bottle containing no acid is for the analysis of pH, total suspended solids (TSS), total dissolved solids (TDS), nitrite, and nitrate. Also, obtain another set of samples from sample ports S1, S2, and S3 and set aside for later delivery to NCEL. These samples do not have to be kept on ice. All sample bottles shall be labeled with sample port number, time, and date.

6. Obtain additional samples for NNSY and NCEL from sample ports S3, S4, S5, and S6 at about the following intervals of the recycling test period: 25, 50, 75, and 100 percent. The shop 41 hydroblast crew can give an accurate status on percentage of boiler tubes cleaned and to be cleaned.

7. Record the flow totalizers readings during the whole hydroblast process and the sampling time. Also note any pressure drop across filters and any other pertinent information; such as any water leaks, filter changes, or operating condition changes.

8. Switch filter trains in the event of any filter plug-up. Note the pressure drop, totalizer reading, and the micron size of the plugged-up filter. Place used filters in a ziploc bag for possible chemical analysis.

One important consideration was not to allow any disruptions of the boiler cleaning operations by failure of our recycling system. Therefore, the valve arrangement of our setup, shown in Figure 1, was designed to switch from a recycling mode to a normal disposal mode in less than 1 minute. This valve arrangement and the five-minute capacity of the feed solution tank in the hydroblast unit ensured no disruptions. The detailed test conditions of all three series are given in Table 1.

First Series of Field Tests

Test Setup. The first series of recycling tests conducted were for wastewater from the first washing of boiler 1A - USS Dahlgren. Figure 1 is a schematic of the test setup used. Figures 2 thru 5 show the major hardware setup. Figure 2 shows the bilge pump connections to collect hydroblasting wastewater and deliver it to our settling tank. It is important to collect the hydroblasting wastewater separately; otherwise it will mix with other bilge wastes. The mixed or combined waste streams are too complicated to be treated. Figure 3 shows the 2,500-gallon capacity settling tank borrowed from NNSY for these tests. The only modification was to weld an 8-inch vertical nipple at the bottom inside the tank for discharge. This provided an intake to our recycling pump above the tank bottom and thus prevented any of the settled particulates from being reintroduced in the recycled wastewater. Also, the incoming boiler wastewater was introduced at the top of the settling tank to prevent any disturbance of the settled particulates.

The settling tank was charged with 1500 gallons of boiler wastewater. The rationale for using 1500 gallons for recycling was that this is one-tenth of the estimated 15,000 gallons required for total boiler cleaning. This ratio of 10 to 1 would meet the goal for 90 percent in wastewater reduction. Figure 4 shows the two parallel filter trains used in the test. Figure 5 shows the hydroblast unit on pier side with the USS Dahlgren in the background. Our recycling unit was operated simultaneously with the hydroblast unit.

Two flow totalizers were used to measure accurately the total gallons required for boiler tube cleaning. One totalizer was placed at the clean feedwater inlet to the hydroblast unit. This measured the initial freshwater feed through the boiler to the settling tank and any make-up freshwater feed required during the cleaning operation. The second flow totalizer was positioned at the recycling pump and measured the total gallons recycled. The sum of the two net readings was the total gallons used for boiler tube cleaning.

Pressure gauges were placed before and after every filter to measure any pressure drop during the entire cleaning process. The filters used for these tests were about 7 inches in diameter by 30 inches long with a filter surface area of about 633 square inches. This compares with the 5-inch diameter and 7-inch long filters with about 90 square inches of surface area used in the pilot scale tests (Ref 1). Two parallel filter trains, each with a 50 micron filter followed by a 10-micron or a 25-micron filter, were used to ensure continuous recycling by simply switching from one to another in the event of filter plug-up. The larger filter area was to minimize or perhaps eliminate filter changes for one complete boiler cleanup.

Test Operations. The hydroblast operation was initiated at 1700, 25 April 1989 and was completed by 0245, 27 April 1989 for a total duration of about 36 hours. Three shifts were in effect. The hydroblast

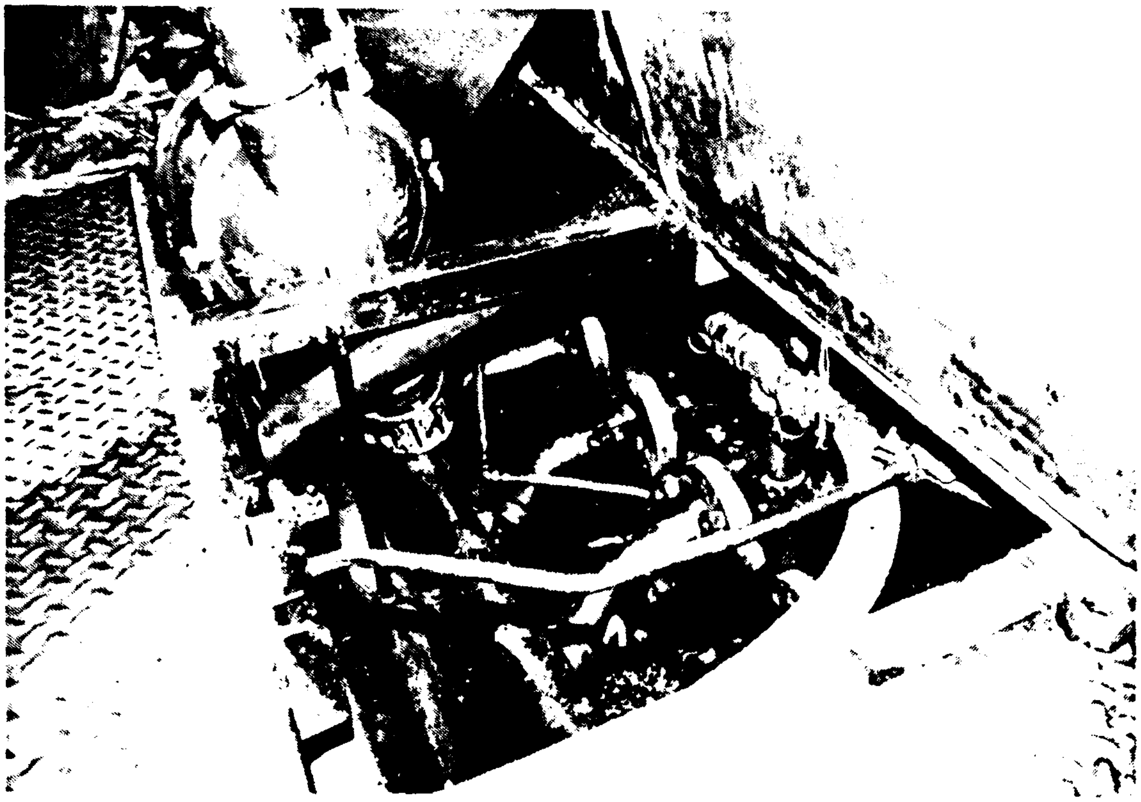

Figure 2. Bilge pump to collect hydroblasting wastewater separately.

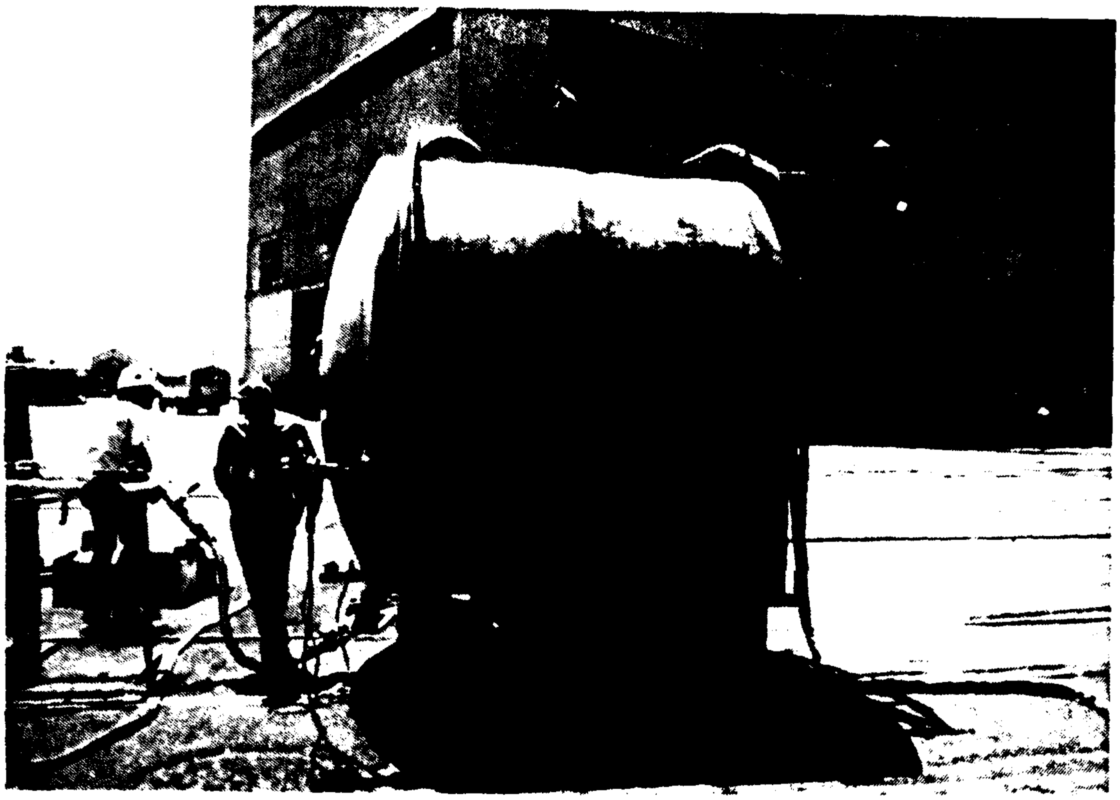

Figure 3. The 2500-gal wastewater settling tank.

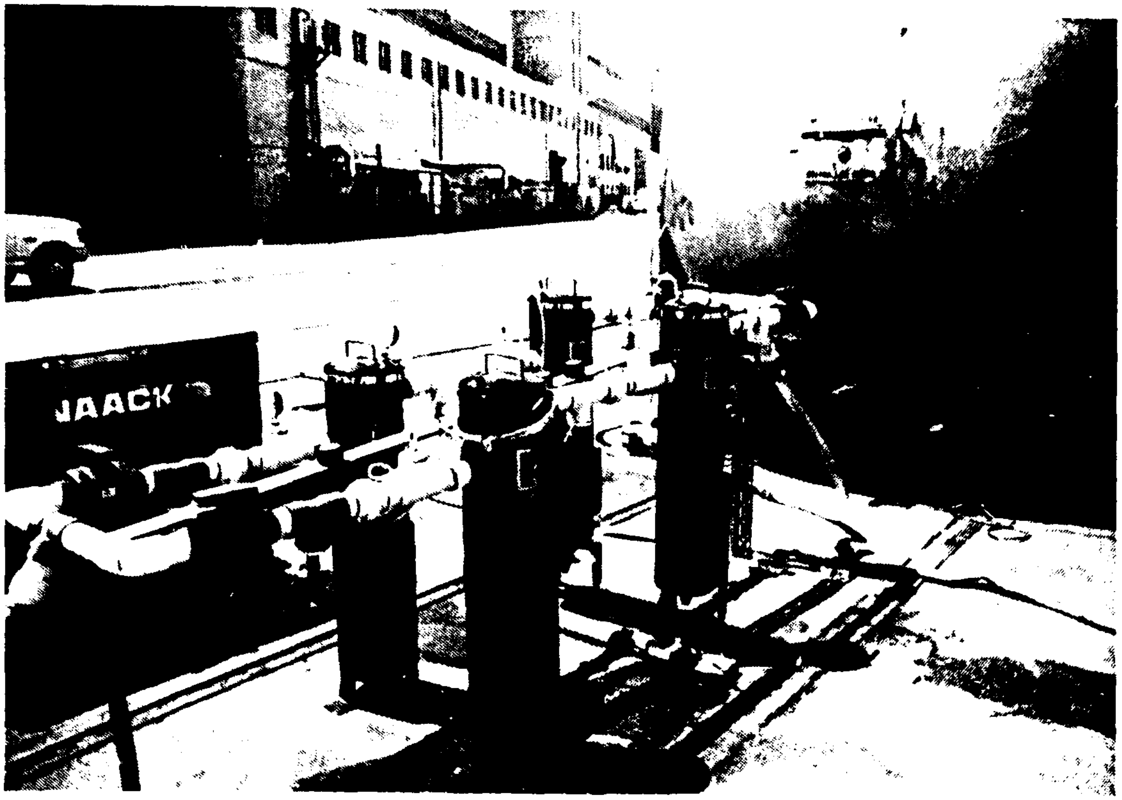

Figure 4. Two parellel filter trains.

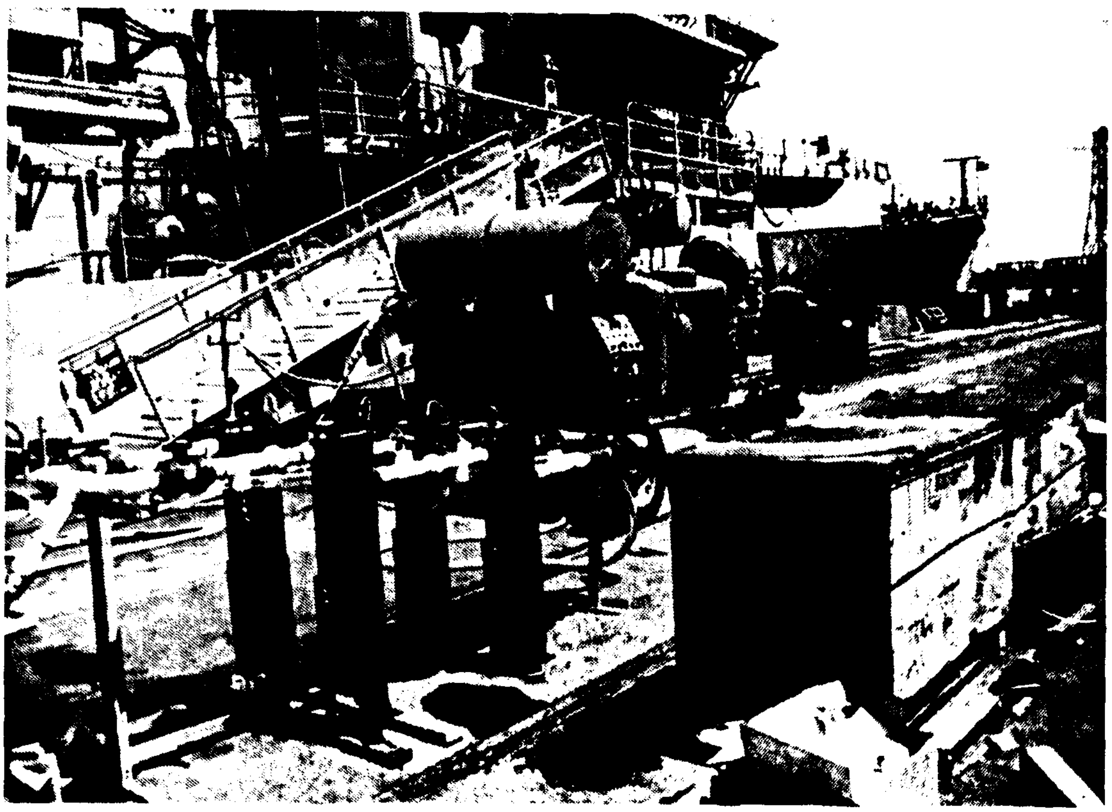

Figure 5. Treated wastewater recycled to hydroblast unit.

unit had several minor problems that were fixed within 1 or 2 hours, such as: (1) failure of the diesel engine to drive the fivestage pump to the required 10,000-psig water jet pressure, (2) sudden failure of the pressure relief valve, and (3) breakdown of a piston phenolic seal on the high pressure side.

Subsequently, the hydroblast operation as well as the recycling system proceeded smoothly. At the end, only 7,950 gallons, not 15,000, were required to clean this size boiler. As a result, the wastewater collected was recycled only three times, which presenteu a volume reduction of 75 percent. There were two problems observed during the recycling test. First, poor connections between water drum, tube walls, and the bilge pump causing wastewater to leak into the water drum and bilge. The second problem was a 5 °F rise in the recycled wastewater. A certain temperature rise is expected due to the pressurization of water to 10,000 psig. Even this small temperature rise caused undue hardship for the gun operator inside the boiler drum. This problem was later solved by adding a heat exchanger with seawater as the cooling medium.

Filter performance during the entire recycling process was flawless. No pressure drop across any of the filters was indicated by the pressure gauges. After recycling 2600 gallons, a decision was made to replace the 50 micron/10 micron filter combination with a new 50 micron/25 micron filter combination. The used 50 and 10 micron filters looked to be in very good condition but discolored due to the turbidity of the wastewater. A sample set was taken just before the filter switch and another set after about 800 gallons of wastewater was recycled with the 50/25 micron filters. At this point, a 10 micron filter was added in series after the 25 and 50 micron filters. An additional 1,000 gallons of wastewater was recycled and samples obtained at the end of the hydroblast process. Again, the filters were removed and looked to be in remarkably good shape.

The boiler tube surface conditions were examined by a boiler inspector from the Naval Ship Systems Engineering Station (NAVSSES), Philadelphia, after the recycling and hydroblasting operations. Boiler tube cleaning personnel marked the sets of tubes in the order cleaned. The first set of tubes was cleaned with normal fresh feed solution until the settling tank was charged-up. The boiler tubes cleaned thereafter were with an increasing degree of recycled wastewater. At the conclusion of the hydroblast cleaning, the boiler tubes were inspected by a boiler inspector from NAVSSES, visually and with the standard borescope method. The inspector declared that there was no difference found in the boiler tubes cleaned with the fresh feed solution and those cleaned with the recycled wastewater. Thus the boiler cleaning passed inspection. Furthermore, the high pressure pump as well as the lance orifices operated normally during the whole process.

Characteristics of Wastewater. As mentioned above, the first series of field tests were done for the first washing wastewater of Boiler 1A. The characteristics of the wastewater before and after settling and filtration were analyzed by the NNSY chemical laboratory. The results are given in Tables 2 through 7 for the various sample ports and times. The turbidity and suspended solids were analyzed by the BTC Environmental Laboratory, Ventura, CA. The results are given in Table 8, which also

Table 2

SAMPLE ANALYSIS FOR FIRST WASH
BOILER 1A, USS DAHLGREN AT 2210-4/25

Analysis for	Units	Sample Results			
		STK-1300 4/25	S1-2210 4/25	S2-2210 4/25	S3-2210 4/25
pH		6.97	7.51	7.40	7.93
Oil and Grease	mg/1	<5.0	<5.0	<5.0	<5.0
Total Suspended Solids	mg/1	< 4.0	< 4.0	< 4.0	160
Total Dissolved Solids	mg/1	1200	120	960	1100
Nitrite	mg/1	880	27	610	860
Nitrate	mg/1	5	1	230	10
METALS					
Cadmium	mg/1	0.001	0.002	0.003	0.005
Chromium	mg/1	0.011	0.010	0.010	0.025
Copper	mg/1	0.080	0.028	0.011	30
Lead	mg/1	0.027	0.032	< 0.01	0.92
Mercury	mg/1	<0.0002	<0.0002	<0.0002	<0.0002
Iron	mg/1	0.074	0.60	0.10	4.80
Nickel	mg/1	0.007	0.022	< 0.003	0.082
Sodium	mg/1	500	30	350	420
Zinc	mg/1	0.047	0.37	0.032	0.35

Remarks:

STK - Settling tank residue contents before experiment.

S1 - Clean feedwater.

S2 - Clean feedwater and sodium nitrite mixture.

S3 - Wastewater from boiler before settling tank.

2210, 4/25 - Sampling time at 2210, April 25.

Table 3

SAMPLE ANALYSIS FOR FIRST WASH
BOILER 1A, USS DAHLGREN AT 0900-4/26

Analysis for	Units	Sample Results S3-0900 4/26	S4A-0900 4/26	S5A-0900 4/26	S6A-0900 4/26
pH		7.68	7.63	7.67	7.67
Oil and Grease	mg/1	<5.0	<5.0	<5.0	<5.0
Total Suspended Solids	mg/1	63	16	21	20
Total Dissolved Solids	mg/1	800	840	840	830
Nitrite	mg/1	590	560	530	500
Nitrate	mg/1	6	60	140	180
METALS					
Cadmium	mg/1	0.006	0.003	0.004	0.003
Chromium	mg/1	0.043	0.011	0.38	0.015
Copper	mg/1	54	1.46	5.48	5.15
Lead	mg/1	1.06	0.14	0.26	0.50
Mercury	mg/1	<0.0002	<0.0002	<0.0002	<0.0002
Iron	mg/1	10.1	0.37	5.94	0.83
Nickel	mg/1	0.19	0.011	0.16	0.024
Sodium	mg/1	310	340	350	330
Zinc	mg/1	0.46	0.11	0.18	0.13

Remarks:

S3 - Wastewater from boiler before settling tank.

S4A - Wastewater from boiler after settling tank.

S5A - Wastewater from boiler after 50 micron filter.

S6A - Wastewater from boiler after 10 micron filter.

0900, 4/26 - Sampling time at 0900, April 26.

Table 4

SAMPLE ANALYSIS FOR FIRST WASH
BOILER 1A, USS DAHLGREN AT 1045-4/26

Analysis for	Units	Sample Results			
		S3-1045 4/26	S4A-1045 4/26	S5A-1045 4/26	S6A-1045 4/26
pH		8.00	7.77	7.75	7.77
Oil and Grease	mg/1	<5.0	<5.0	<5.0	<5.0
Total Suspended Solids	mg/1	85	6	< 4.0	< 4.0
Total Dissolved Solids	mg/1	800	920	860	800
Nitrite	mg/1	590	420	500	490
Nitrate	mg/1	6	180	190	190
METALS					
Cadmium	mg/1	<0.001	0.003	0.002	0.002
Chromium	mg/1	< 0.002	0.013	0.012	0.012
Copper	mg/1	1.59	1.32	1.18	2.10
Lead	mg/1	0.036	0.17	0.15	0.21
Mercury	mg/1	<0.0002	<0.0002	<0.0002	<0.0002
Iron	mg/1	0.028	0.45	0.33	0.45
Nickel	mg/1	0.022	0.011	0.006	0.052
Sodium	mg/1	320	330	360	330
Zinc	mg/1	0.090	0.14	0.12	0.11

Remarks:

S3 - Wastewater from boiler before settling tank.

S4A - Wastewater from boiler after settling tank.

S5A - Wastewater from boiler after 50 micron filter.

S6A - Wastewater from boiler after 10 micron filter.

1045, 4/26 - Sampling time at 1045, April 26.

Table 5

SAMPLE ANALYSIS FOR FIRST WASH
BOILER 1A, USS DAHLGREN AT 1510-4/26

Analysis for	Units	Sample Results			
		S3-1510 4/26	S4A-1510 4/26	S5A-1510 4/26	S6A-1510 4/26
pH		8.01	7.84	8.01	8.00
Oil and Grease	mg/1	<5.0	<5.0	<5.0	<5.0
Total Suspended Solids	mg/1	140	53	49	38
Total Dissolved Solids	mg/1	920	820	930	890
Nitrite	mg/1	410	630	590	580
Nitrate	mg/1	6	6	6	70
METALS					
Cadmium	mg/1	0.004	0.003	0.003	0.007
Chromium	mg/1	0.021	0.015	0.013	0.035
Copper	mg/1	8.10	8.00	6.29	5.97
Lead	mg/1	0.58	0.41	0.31	0.86
Mercury	mg/1	<0.0002	<0.0002	<0.0002	<0.0002
Iron	mg/1	2.12	1.23	0.82	2.03
Nickel	mg/1	0.034	0.025	0.020	0.043
Sodium	mg/1	300	340	300	360
Zinc	mg/1	0.38	0.16	0.14	0.37

Remarks:

S3 - Wastewater from boiler settling tank.

S4A - Wastewater from boiler after settling tank.

S5A - Wastewater from boiler after 50 micron filter.

S6A - Wastewater from boiler after 10 micron filter.

1510, 4/26 - Sampling time at 1510, April 26.

Table 6

SAMPLE ANALYSIS FOR FIRST WASH
BOILER 1A, USS DAHLGREN AT 1830-4/26

Analysis for	Units	Sample Results			
		S3-1830 4/26	S4A-1830 4/26	S5A-1830 4/26	S6A-1830 4/26
pH		7.68	7.75	7.66	7.74
Oil and Grease	mg/1	12	<5.0	<5.0	<5.0
Total Suspended Solids	mg/1	33	52	46	35
Total Dissolved Solids	mg/1	940	950	960	940
Nitrite	mg/1	650	690	650	530
Nitrate	mg/1	6	7	6	8
METALS					
Cadmium	mg/1	0.003	0.004	0.003	0.001
Chromium	mg/1	0.087	0.009	0.017	0.015
Copper	mg/1	5.03	14.8	9.72	6.98
Lead	mg/1	0.42	0.57	0.49	0.42
Mercury	mg/1	<0.0002	<0.0002	<0.0002	<0.0002
Iron	mg/1	3.30	1.98	1.26	0.88
Nickel	mg/1	0.006	0.054	0.035	0.029
Sodium	mg/1	340	370	310	350
Zinc	mg/1	0.31	0.29	0.20	0.17

Remarks:

S3 - Wastewater from boiler before settling tank.

S4A - Wastewater from boiler after settling tank.

S5A - Wastewater from boiler after 50 micron filter.

S6A - Wastewater from boiler after 10 micron filter.

1830, 4/26 - Sampling time at 1830, April 26.

Table 7

SAMPLE ANALYSIS FOR FIRST WASH
BOILER 1A, USS DAHLGREN AT 0245-4/27

Analysis for	Units	Sample Results S3-0245 4/27	S4A-0245 4/27	S5A-0245 4/27	S6A-2450 4/27	S7A-0245 4/27
pH		7.72	7.88	7.92	7.93	7.96
Oil and Grease	mg/1	<5.0	<5.0	<5.0	<5.0	<5.0
Total Suspended Solids	mg/1	200	12	4	< 4.0	7
Total Dissolved Solids	mg/1	930	970	950	960	970
Nitrite	mg/1	570	650	610	560	530
Nitrate	mg/1	6	30	130	140	80
METALS						
Cadmium	mg/1	0.022	0.003	0.002	0.003	0.001
Chromium	mg/1	0.053	0.012	0.009	0.011	0.013
Copper	mg/1	9.15	2.21	1.37	1.10	1.96
Lead	mg/1	0.94	0.20	0.15	0.13	0.18
Mercury	mg/1	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Iron	mg/1	4.54	0.44	0.47	0.28	0.41
Nickel	mg/1	0.12	< 0.003	0.013	0.009	0.010
Sodium	mg/1	320	360	330	360	320
Zinc	mg/1	0.35	0.11	0.10	0.11	0.13

Remarks:

S3 - Wastewater from boiler before settling tank.

S4A - Wastewater from boiler after settling tank.

S5A - Wastewater from boiler after 50 micron filter.

S6A - Wastewater from boiler after 25 micron filter.

S7A - Wastewater from boiler after 10 micron filter.

0245, 4/27 - Sampling time at 0245, April 27.

TABLE 8

TURBIDITY AND SUSPENDED SOLIDS FOR FIRST WASH

BOILER 1A, USS DAHLGREN, AT NNSY

Sample		Turbidity BTC NTU	Suspended Solids mg/l BTC[1]	NNSY[2]
STK-1300	4/25	0.13	3.0	< 4.0
S1-2210	4/25	0.14	<0.01	< 4.0
S2-2210	4/25	0.15	5.0	< 4.0
S3-2210	4/25	0.60	204	160
S3-0900	4/26	0.58	41	63
S4A-0900	4/26	0.315	21	16
S5A-0900	4/26	0.30	22	21
S6A-0900	4/26	0.36	22	20
S3-1045	4/26	0.45	64	85
S4A-1045	4/26	0.25	7.0	6
S5A-1045	4/26	0.26	10	< 4.0
S6A-1045	4/26	0.24	5.0	< 4.0
S3-1510	4/26	0.51	9.0	140
S4A-1510	4/26	0.38	58	53
S5A-1510	4/26	0.425	51	49
S6A-1510	4/26	0.34	38	38
S3-1830	4/26	0.45	31	33
S4A-1830	4/26	0.51	55	52
S5A-1830	4/26	0.44	45	46
S6A-1830	4/26	0.43	33	35
S3-0245	4/27	0.68	165	200
S4A-0245	4/27	0.26	14	12
S5A-0245	4/27	0.23	7.0	4
S6A*-0245	4/27	0.35	27	< 4.0
S7A-0245	4/27	0.29	15	7

Remarks

1. Analysis Performed by BTC Environmental, Ventura, CA.
2. Analysis performed by Environmental Chemistry Laboratory, NNSY.

STK - Settling tank residue contents before experiment.
S1 - Clean Feedwater.
S2 - Clean Feedwater and sodium nitrite mixture.
S3 - Wastewater from boiler before settling tank.
S4A - Wastewater from boiler after settling tank.
S5A - Wastewater from boiler after 50 micron filter.
S6A - Wastewater from boiler after 10 micron filter.
S6A* - Wastewater from boiler after 25 micron filter.
S7A - Wastewater from boiler after 10 micron filter.

includes the suspended solids analysis performed by NNSY chemical laboratory. The particle size measurements were done by the Particle Measurement Technology Co., Ventura, CA. The results are shown in Tables 9, 10, 11 and 12. The following are the summarized results of this first series of tests. Discussion of the overall results of all three series of tests will be given later.

pH. Tables 2 through 7 show that the pH remained in a narrow range of 7.4 to 8.01 throughout the whole cleaning process. Settling and filtration had no effect on the pH value.

Oil and Grease. Tables 2 through 7 show that oil and grease remained below 5.0 mg/L throughout the test except for one reading of 12 mg/L measured at sample port S3 at 1830 of April 26. One explanation given by NNSY chemical laboratory is the possibility that during the particular sample taking, some oil and grease got into the sample from the gloves worn by the sample taker.

Total Suspended Solids (TSS). Tables 2 through 7 show the total suspended solids analyzed by the NNSY chemical laboratory. Table 8 shows the total suspended solids performed by NNSY to be generally in good agreement with those by the BTC Laboratory. The settling tank had a marked effect on allowing particulates to settle (S4 versus S3) except for the samples taken at 1830 hours of April 26. The only explanation would be a disturbance that allowed settled particulates to get back into suspension. Table 11 also shows an increase in the number of particles, especially in the 10 to 25 micron range after settling (S4 versus S3). It should be noted that any disturbance of the settled particulates will increase the downstream suspended solids concentration. That is why sometimes the total suspended solids were more at sample port S4 than sample port S3.

Total Dissolved Solids (TDS). Tables 2 through 7 show that the clean feed water (S1) had the lowest content of TDS, while the feed solution (S2) had a significant increase in TDS due to addition of sodium nitrite. The TDS of S3 to S7A remained in a range of 800 to 1100 ppm which indicates that settling and filtration had no effect on TDS.

Nitrite. According to NAVSEA Instructions (Ref 2), one pound of sodium nitrite should be added to 100 gallons of potable water for the preparation of the hydroblast feed solution. This is equivalent to 1,200 ppm of sodium nitrite or 800 ppm of nitrite concentration. Tables 2 through 7 show the nitrite concentration ranged from a low of 400 to a high of 860 mg/L. However, in each particular sampling time, the nitrite concentration did not decrease during settling and filtering (see nitrites at S3, S4, S5, S6, and S7). In other words, no loss of nitrite was experienced throughout the test.

Nitrate. The majority of data indicate that nitrate was less than 10 ppm. If nitrite (NO_2) was not oxidated to nitrate (NO_3), it is expected that the nitrate concentration should be very low. We know that nitrite may interfere with the analysis of nitrate. This may explain why a number of samples show higher nitrate concentrations than expected.

TABLE 9

PARTICLE SIZE MEASUREMENT FOR FIRST WASH

BOILER 1A, USS DAHLGREN, AT 2210-4/25

SIZE RANGE	SAMPLE S1-2210 4/25	CPPM	SAMPLE S2-2210 4/25	CPPM	SAMPLE S3-2210 4/25	CPPM
10 - 25μm	12,503	0.35	45,608	1.27	10,453,560	292.49
25 - 50μm	2,147	0.59	2,812	0.77	167,520	46.11
50 - 75μm	21	0.07	88	0.11	2,600	3.31
75 - 100μm	63	0.46	340	1.18	8,000	27.97
100 - 125μm	2	0.01	68	0.50	240	1.78
> 125μm	0	0.00	20	0.28	0	0.00
TOTAL	14,736	1.48	48,936	4.11	10,631,920	371.66

Remarks:

S1 - Clean Feedwater.

S2 - Clean Feedwater and sodium nitrite mixture.

S3 - Wastewater from boiler before settling tank.

TABLE 10

PARTICLE SIZE MEASUREMENT FOR FIRST WASH
BOILER 1A, USS DAHLGREN, AT 1045-4/26

SIZE RANGE	SAMPLE S3-1045 4/26	CPPM	SAMPLE S4A-1045 4/26	CPPM
10 - 25μm	5,687,930	159.14	796,960	22.29
25 - 50μm	276,180	76.03	49,144	13.53
50 - 75μm	1,090	1.38	176	0.22
75 - 100μm	3,020	22.44	388	1.35
100 - 125μm	270	2.00	0	0.00
> 125μm	490	7.01	0	0.00
TOTAL	5,968,980	268.00	846,668	37.39

SIZE RANGE	SAMPLE S5A-1045 4/26	CPPM	SAMPLE S6A-1045 4/26	CPPM
10 - 25μm	579,626	16.24	191,636	5.36
25 - 50μm	12,396	3.41	57,932	15.94
50 - 75μm	38	0.04	1,528	1.94
75 - 100μm	140	0.48	4,172	14.59
100 - 125μm	18	0.13	52	0.38
> 125μm	0	0.00	0	0.00
TOTAL	592,218	20.27	255,320	38.21

Reamarks:

S3 - Wastewater from boiler before settling tank.

S4A - Wastewater from boiler after settling tank.

S5A - Wastewater from boiler after 50 micron filter.

S6A - Wastewater from boiler after 10 micron filter.

TABLE 11

PARTICLE SIZE MEASUREMENT FOR FIRST WASH
BOILER 1A, USS DAHLGREN, AT 1830-4/26

SIZE RANGE	SAMPLE S3-1830 4/26	CPPM	SAMPLE S4A-1830 4/26	CPPM
10 - 25μm	4,198,128	117.46	6,976,224	195.19
25 - 50μm	101,016	27.80	28,096	7.73
50 - 75μm	24	0.03	32	0.04
75 - 100μm	256	0.89	400	1.39
100 - 125μm	16	0.11	64	0.47
> 125μm	0	0.00	0	0.00
TOTAL	4,299,440	146.29	7,004,816	204.82

SIZE RANGE	SAMPLE S5A-1830 4/26	CPPM	SAMPLE S6A-1830 4/26	CPPM
10 - 25μm	4,873,680	136.37	3,726,600	104.27
25 - 50μm	61,040	16.81	83,369	22.95
50 - 75μm	96	0.13	112	0.14
75 - 100μm	240	0.84	248	0.86
100 - 125μm	40	0.30	8	0.11
> 125μm	0	0	0	0.00
TOTAL	4,935,096	154.45	3,810,336	128.33

Reamarks:

S3 - Wastewater from boiler before settling tank.

S4A - Wastewater from boiler after settling tank.

S5A - Wastewater from boiler after the second new 50 micron filter.

S6A - Wastewater from boiler after 25 micron filter.

TABLE 12

PARTICLE SIZE MEASUREMENT FOR FIRST WASH
BOILER 1A, USS DAHLGREN, AT 0245-4/27

SIZE RANGE	SAMPLE S3-0245 4/27	CPPM	SAMPLE S4A-0245 4/27	CPPM	SAMPLE S5A-0245 4/27	CPPM
10 - 25μm	9,789,640	273.91	1,347,192	37.69	365,220	10.22
25 - 50μm	206,120	56.74	92,392	25.43	61,992	17.06
50 - 75μm	1,040	1.32	152	0.19	684	0.87
75 - 100μm	2,720	9.51	236	0.82	1,316	4.60
100 - 125μm	160	1.18	12	0.09	36	0.26
> 125μm	40	0.57	0	0.00	0	0.00
TOTAL	9,999,720	343.23	1,439,984	59.22	429,248	33.01

SIZE RANGE	SAMPLE S6A-0245 4/27	CPPM	SAMPLE S7A-0245 4/27	CPPM
10 - 25μm	1,562,288	43.72	921,244	25.77
25 - 50μm	18,144	5.00	43,972	12.10
50 - 75μm	104	0.14	180	0.23
75 - 100μm	648	2.27	464	1.62
100 - 125μm	80	0.60	52	0.38
> 125μm	16	0.23	0	0
TOTAL	1,581,280	51.96	956,912	40.10

Remarks:

S3 - Wastewater from boiler before settling tank.

S4A - Wastewater from boiler after settling tank.

S5A - Wastewater from boiler after the second new 50 micron filter.

S6A - Wastewater from boiler after 25 micron filter.

S7A - Wastewater from boiler after the second new 10 micron filter.

Heavy Metals. All the metals in Tables 2 to 7 are in very low concentrations (well below 1 mg/L with the filtered wastewater showing the least) except for iron and copper. Iron in the wastewater before settling remained below 10.1 mg/L. After filtration, iron in the wastewater remained below 2.03 mg/L. It should be noted that EPA has no discharge requirement for iron.

Copper, on the other hand, showed concentrations ranging from 54 to 1.59 mg/L before settling. After filtration, the concentrations ranged from 6.98 to 1.96 mg/L.

Based on the discharge limits of heavy metals to the sewer system or public sanitary plant at Naval Shipyards, two heavy metals, copper and lead with discharge limits at 2-3 mg/L and 0.05 mg/L respectively, need to be further reduced. It is planned to combine the finally recycled hydroblasting wastewater (only 10 percent of the total hydroblasting wastewater) with other sodium nitrite waste streams for treatment.

Turbidity. The turbidity method is based upon the intensity of light scattered by the sample as compared to a known standard. The higher the intensity of scattered light, the higher the turbidity. Readings are made in NTU's (Nephelometer Turbidity Units) on a nephelometer calibrated with a standard suspension of Formazin.

Table 8 shows the turbidity results as performed on samples delivered to BTC environmental laboratory. It shows that a larger TSS causes a high turbidity. Although the recycled wastewater was still turbid, its reuse to clean the boiler tubes proved to be acceptable and caused no problem.

Particle Size Measurement. The sample for particle size measurement was stirred for a minimum of 2 minutes prior to analysis and continuously stirred throughout testing. A 100 ml portion was analyzed from each preparation, and particle counts were subsequently factored to obtain statistical equivalency to 100 ml of the actual sample. This data is given along with the calculated parts per million (CPPM), which is based on the mean particle size of each size range (see Reference 1 for more details of calculations). Table 9 shows that the TSS was increased from the clean potable water to the feed solution after adding sodium nitrite and further increased in the wastewater after leaving the boiler tubes. The cloth bag filters were used to remove different size ranges of suspended solids. The filters have a normal 50 percent efficiency at the rated size. For example, a 50-micron filter has a 50 percent probability to collect the 50 micron size particles. The efficiency is higher as the micron size increases. Also, the efficiency increases as the filter builds a "cake" of particles on its surface. In our tests, the used filters exhibited no "cake" and were virtually empty except for the particles trapped in the cloth material.

Second Series of Field Tests

Test Set-Up. The second series of field tests were for the second washing of Boiler 1A, USS Dahlgren. Referring to Figure 1, the apparatus and equipment were the same as used in the first series except for two enhancements. First, a heat exchanger was added to cool the wastewater as it was pumped out of the boiler and before entering the settling tank. This solved the problem of the 5 °F temperature rise experienced by the boiler cleaning personnel due to the pressurization of the recycled wastewater. Second, a smaller settling tank of 600 gallons instead of 2,500 gallons was utilized. Figure 6 shows the configuration of the settling tank. Modification for this off-the-shelf tank was the 10-inch diameter pipe used as a baffle. The pipe was capped off at the bottom. This capped end was about 5 inches above tank bottom. One-inch diameter holes were drilled just above the capped end which allowed the wastewater to flow horizontally into the tank without disturbing the already settled particulates. The top end of the pipe had the proper attachments to the incoming boiler wastewater hose as well as a vent shown in Figure 6. The effluent from this settling tank was connected through the recycling pump to the filter trains. Two connections of the effluent were made as shown, one at mid-height and the other toward the top of the tank. This provided the possible variations of the wastewater level to be pumped out. The middle baffle in the 600-gallon tank decreased the disturbance of wastewater inside the tank.

Test Operations. The hydroblast operations commenced at 1455, 20 June 1989 and were concluded at 0700, 22 June 1989. There were two minor problems in the hydroblasting unit: the diesel engine failed to drive the high pressure pump, and the high pressure hydroblast gun had to be replaced.

The recycling equipment and apparatus performed very well except for one slight problem. The vent of the 10-inch baffle pipe in the 600-gal settling tank was not adequate to relieve the high pressure of the wastewater from the boiler. As the settling tank filled up with more wastewater, so did the baffle pipe. Subsequently, some wastewater residue was forced out of the 2-inch vent. This problem was readily solved by attaching a flexible hose from the vent back into the 18-inch access hatch.

At the conclusion of this recycling experiment, nine cycles were achieved with no apparent adverse effects on the high pressure pump, the orifice, or the boiler tubes. Two boiler inspectors completed their standard inspection procedures and accepted the cleaning results. Only one set of filters was used in this experiment, namely, a 50-micron and a 10-micron size filter, and they appeared to be in remarkably good shape. It should be noted that nine recycles of the collected wastewater of 600 gallons represented a 90 percent reduction of the total wastewater. That is, at least 6,000 gallons of fresh feed solution in addition to make-up water would have been consumed if there had been no recycling.

Characteristics of Wastewater. As in the first series of field tests, the characteristics of the second series test were extensively analyzed by the NNSY chemical laboratory. The results are shown in Tables 13 through 18 for the various ports and times. The turbidity and suspended solids were analyzed by the BTC Laboratory, Ventura, CA, and the results are shown in Table 19. The analysis of suspended solids by the NNSY chemical laboratory is also shown in Table 19. The particle size measurements were done by the Particle Measurement Technology Co, Ventura, CA. The results are given in Tables 20 to 22. The following is the summary of the analytical data and the results.

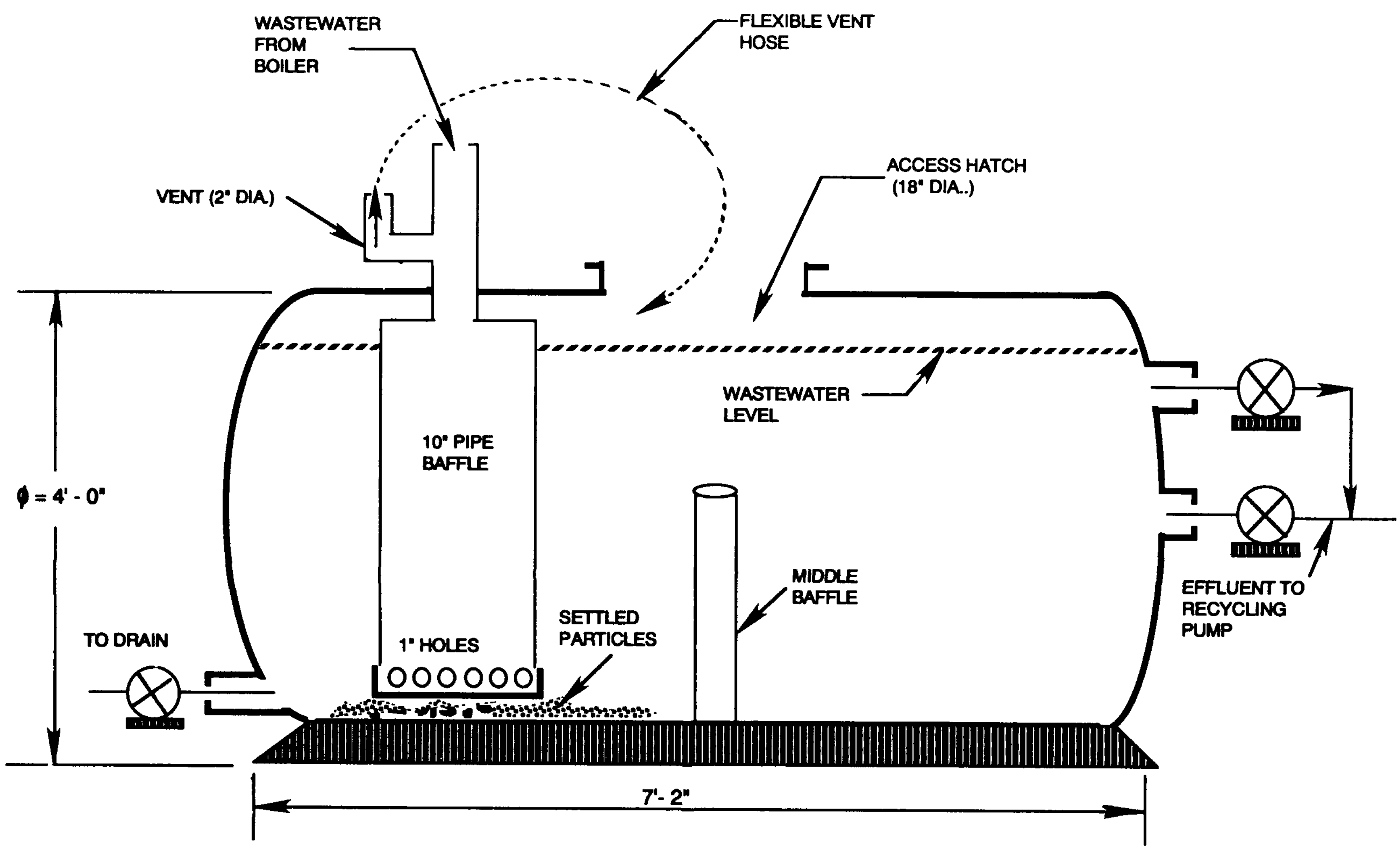

Figure 6. Configuration of the 600 gallon settling tank.

Table-13

SAMPLE ANALYSIS FOR SECOND WASH
BOILER 1A, USS DAHLGREN AT 2115-6/20

Analysis for	Units	Sample Results		
		S1-2115 6/20	S2-2115 6/20	S3-2115 6/20
pH		8.70	7.77	7.14
Oil and Grease	mg/1	<5.0	<5.0	<5.0
Total Suspended Solids	mg/1	< 4.0	< 4.0	13
Total Dissolved Solids	mg/1	38	2100	1900
Nitrite	mg/1	< 1	1430	1150
Nitrate	mg/1	< 1	50	7
METALS				
Cadmium	mg/1	0.030	<0.001	0.008
Chromium	mg/1	0.004	< 0.004	0.012
Copper	mg/1	0.060	0.014	0.71
Lead	mg/1	0.020	< 0.02	0.088
Mercury	mg/1	< 0.0002	< 0.0002	< 0.0002
Iron	mg/1	4.4	0.13	1.5
Nickel	mg/1	0.013	< 0.004	0.052
Sodium	mg/1	1.1	660	700
Zinc	mg/1	1.1	0.053	0.34

Remarks:

S1 - Clean Feedwater.

S2 - Clean Feedwater and sodium nitrite mixture.

S3 - Wastewater from boiler before settling tank.

Table 14

SAMPLE ANALYSIS FOR SECOND WASH
BOILER 1A, USS DAHLGREN AT 1010-6/21

Analysis for	Units	Sample Results			
		S3-1010 6/21	S4-1010 6/21	S5-1010 6/21	S6-1010 6/21
pH		7.14	7.14	7.15	7.14
Oil and Grease	mg/1	<5.0	<5.0	<5.0	<5.0
Total Suspended Solids	mg/1	23	14	11	7
Total Dissolved Solids	mg/1	1100	1400	1400	1300
Nitrite	mg/1	1000	1200	1000	1100
Nitrate	mg/1	4	5	70	5
METALS					
Cadmium	mg/1	0.010	0.008	0.006	0.004
Chromium	mg/1	0.022	0.011	0.010	0.010
Copper	mg/1	1.2	0.38	0.39	0.33
Lead	mg/1	0.22	0.074	0.089	0.075
Mercury	mg/1	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Iron	mg/1	2.7	0.40	0.42	0.39
Nickel	mg/1	0.063	0.030	0.035	0.022
Sodium	mg/1	420	460	480	500
Zinc	mg/1	0.25	0.14	0.16	0.15

Remarks:

S3 - Wastewater from boiler before settling tank.

S4 - Wastewater from boiler after settling tank.

S5 - Wastewater from boiler after 50 micron filter.

S6 - Wastewater from boiler after 10 micron filter.

Table 15

SAMPLE ANALYSIS FOR SECOND WASH
BOILER 1A, USS DAHLGREN AT 1615-6/21

Analysis for	Units	Sample Results			
		S3-1615 6/21	S4-1615 6/21	S5-1615 6/21	S6-1615 6/21
pH		7.10	7.09	7.10	7.09
Oil and Grease	mg/1	<5.0	<5.0	<5.0	93
Total Suspended Solids	mg/1	33	11	12	13
Total Dissolved Solids	mg/1	1300	1400	1400	1200
Nitrite	mg/1	1000	1200	1200	1200
Nitrate	mg/1	5	5	100	4
METALS					
Cadmium	mg/1	0.015	0.010	0.014	0.010
Chromium	mg/1	0.031	.024	0.018	0.016
Copper	mg/1	2.0	1.4	0.95	0.84
Lead	mg/1	0.25	0.20	0.18	0.20
Mercury	mg/1	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Iron	mg/1	2.8	0.87	0.58	0.59
Nickel	mg/1	0.053	0.047	0.043	0.030
Sodium	mg/1	460	490	440	450
Zinc	mg/1	0.31	0.24	0.21	0.23

Remarks:

S3 - Wastewater from boiler before settling tank.

S4 - Wastewater from boiler after settling tank.

S5 - Wastewater from boiler after 50 micron filter.

S6 - Wastewater from boiler after 10 micron filter.

Table 16

SAMPLE ANALYSIS FOR SECOND WASH
BOILER 1A, USS DAHLGREN AT, 2015-6/21

Analysis for	Units	Sample Results			
		S3-2015 6/21	S4-2015 6/21	S5-2015 6/21	S6-2015 6/21
pH		7.09	7.06	7.09	7.12
Oil and Grease	mg/l	7.5	<5.0	<5.0	< 5
Total Suspended Solids	mg/l	21	18	12	9
Total Dissolved Solids	mg/l	1200	1300	1200	1200
Nitrite	mg/l	1100	1100	1000	1100
Nitrate	mg/l	5	5	5	5
METALS					
Cadmium	mg/l	0.010	< 0.002	< 0.002	0.006
Chromium	mg/l	0.025	< 0.004	< 0.004	0.017
Copper	mg/l	1.1	0.82	0.78	0.65
Lead	mg/l	0.25	0.031	0.042	0.16
Mercury	mg/l	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Iron	mg/l	1.4	0.59	0.57	0.53
Nickel	mg/l	0.048	0.006	0.006	0.037
Sodium	mg/l	460	570	510	470
Zinc	mg/l	0.31	0.27	0.23	0.24

Remarks:

S3 - Wastewater from boiler before settling tank.

S4 - Wastewater from boiler after settling tank.

S5 - Wastewater from boiler after 50 micron filter.

S6 - Wastewater from boiler after 10 micron filter.

Table 17

SAMPLE ANALYSIS FOR SECOND WASH
BOILER 1A, USS DAHLGREN AT, 0700-6/22

		Sample Results			
Analysis for	Units	S3-0700 6/22	S4-0700 6/22	S5-0700 6/22	S6-0700 6/22
pH		7.10	7.09	7.10	7.09
Oil and Grease	mg/l	< 5	<5.0	<5.0	37
Total Suspended Solids	mg/l	190	13	14	20
Total Dissolved Solids	mg/l	1300	1600	1500	1500
Nitrite	mg/l	1400	1300	1100	1000
Nitrate	mg/l	16	2	5	1
METALS					
Cadmium	mg/l	0.013	< 0.002	< 0.002	0.004
Chromium	mg/l	0.062	< 0.004	< 0.004	0.017
Copper	mg/l	1.5	0.83	0.99	0.87
Lead	mg/l	0.51	0.026	0.034	0.17
Mercury	mg/l	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Iron	mg/l	5.8	0.49	0.72	0.59
Nickel	mg/l	0.060	0.006	0.006	0.025
Sodium	mg/l	470	500	490	350
Zinc	mg/l	0.51	0.26	0.30	0.21

Remarks:

S3 - Wastewater from boiler before settling tank.

S4 - Wastewater from boiler after settling tank.

S5 - Wastewater from boiler after 50 micron filter.

S6 - Wastewater from boiler after 10 micron filter.

TABLE 18

ADDITIONAL HEAVY METAL ANALYSIS

SECOND WASH, BOILER 1A, USS DAHLGREN, AT NNSY

	Antimony	Arsenic	Beryllium	Selenium	Silver	Thallium
S2-2115 6/20	< 0.015	0.03	<0.001	< 0.04	< 0.002	< 0.04
S3-1010 6/21	0.042	< 0.03	<0.001	< 0.04	< 0.002	0.054
S6-1010 6/21	0.018	< 0.003	<0.001	< 0.004	< 0.002	< 0.04
S3-2015 6/21	0.019	< 0.03	<0.001	< 0.04	< 0.002	0.093
S6-2015 6/21	0.031	< 0.03	<0.001	< 0.04	< 0.002	0.076
S3-0700 6/22	0.054	< 0.03	<0.001	< 0.04	0.003	0.12
S6-0700 6/22	0.029	< 0.03	<0.001	< 0.04	< 0.002	0.040

Remarks:

S2 - Clean Feedwater and sodium nitrite mixture.

S3 - Wastewater from boiler with no settling.

S6 - Wastewater after settling and after 10 micron filter.

TABLE 19

TURBIDITY AND SUSPENDED SOLIDS FOR SECOND WASH

BOILER 1A, USS DAHLGREN, AT NNSY

Sample		Turbidity BTC NTU	Suspended Solids mg/l BTC[1]	Suspended Solids mg/l NNSY[2]
S1-2215	6/20	0.16	12	< 4
S2-2215	6/20	0.70	2	< 4
S3-2215	6/20	0.40	76	13
S3-1010	6/21	0.39	23	23
S4-1010	6/21	0.23	9	14
S5-1010	6/21	0.18	12	11
S6-1010	6/21	0.20	< 0.01	7
S3-1615	6/21	0.50	44	33
S4-1615	6/21	0.41	22	11
S5-1615	6/21	0.20	18	12
S6-1615	6/21	0.24	6	13
S3-2015	6/21	0.50	29	21
S4-2015	6/21	0.45	20	18
S5-2015	6/21	0.40	1	12
S6-2015	6/21	0.27	7	9
S3-0700	6/22	1.65	383	190
S4-0700	6/22	0.49	14	13
S5-0700	6/22	0.42	11	14
S6-0700	6/22	0.38	25	20

Remarks

1. Analysis Performed by BTC Environmental, Ventura, CA.
2. Analysis performed by Environmental Chemistry Laboratory, NNSY.

S1 - Clean Feedwater.
S2 - Clean Feedwater and sodium nitrite mixture.
S3 - Wastewater from boiler before settling tank.
S4 - Wastewater from boiler after settling tank.
S5 - Wastewater from boiler after 50 micron filter.
S6 - Wastewater from boiler after 10 micron filter.

TABLE 20

PARTICLE SIZE MEASUREMENT FOR SECOND WASH
BOILER 1A, USS DAHLGREN, AT 2115-6/20

SIZE RANGE	SAMPLE S1-2115 6/20	CPPM	SAMPLE S2-2115 6/20	CPPM	SAMPLE S3-2115 6/20	CPPM
10 - 25μm	27,472	0.77	29,980	0.84	3,513,200	98.30
25 - 50μm	4,064	1.12	14,004	3.86	725,800	199.81
50 - 75μm	376	0.48	2,056	2.62	27,400	34.92
75 - 100μm	80	0.28	304	1.06	2,000	6.99
100 - 125μm	16	0.12	40	0.30	1,000	7.43
> 125μm	40	0.57	0	0.00	800	11.46
TOTAL	32,048	3.34	46,384	8.68	4,270,200	358.91

Remarks:

S1 - Clean Feedwater.

S2 - Clean Feedwater and sodium nitrite mixture.

S3 - Wastewater from boiler before settling tank.

pH. The pH remained in a narrow range of 7.06 to 7.14 throughout the test except at the initiation of the test where the pH was 8.7 and 7.77 for the freshwater feed and fresh feed solution, respectively. These pH values are within the wastewater discharge limit of 6 to 9.

Oil and Grease. Oil and grease remained essentially below the 5 mg/L concentration except for two relatively high readings. One reading of 93 mg/L for S6 in table 15 and a second of 37 mg/L for S6 in Table 17. Again, NNSY chemical laboratory personnel rechecked their data and no errors were found in the procedure or calculations. The only plausible answer is that some grease from the sample taker's gloves got into the bottle. Thus, the oil and grease values are also within the limits of 100 mg/L to be discharged to the sanitary plants.

Total Suspended Solids. Laboratory tests in a 14-inch height graduated cylinder showed that a 45-minute settling time was required to obtain a clean solution in the upper half of the cylinder. Our 600-gal settling tank was designed to provide 1 hour of settling time for a wastewater flow of 10 gal/min, or half an hour settling for a flow of 20 gal/min.

Table 19 shows two independent analytical results for total suspended solids as performed by NNSY and the BTC Environmental Laboratory. The total suspended solids in Tables 12 to 17 are included in Table 19. The two sets of results show good agreement and a definite trend of less suspended solids after residence in the settling tank and then after filters. Note that several sets of data of filtration did not show TSS reduction by filters. More checks need to be done in the future.

Total Dissolved Solids. Tables 12 through 17 show that the clean feed water (S1) had the lowest content of TDS. The feed solution (S2) had a significant increase in TDS due to the addition of sodium nitrite. The TDS of S3 to S6 remained in a range of 1100 to 1900 mg/L which indicates that the settling and filtration had no effect on the TDS.

Nitrite. Nitrite concentrations ranged from a low of 1000 mg/L to a high of 1430 mg/L but predominantly around 1100 mg/L. Thus, the sodium nitrite dosage to the fresh feed solution was in excess of the required nitrite concentration of 800 mg/L.

Nitrate. Nitrate concentrations were predominantly around 5 mg/L except for three relatively higher readings of 50, 70 and 100 mg/L. Again, these data indicate that little nitrite was oxidized to nitrate.

Heavy Metals. All the metals in Tables 13 through 18 except copper and iron remained well below 1 mg/L. The filtered wastewater showed the least metal content. Copper ranged from 2.0 to 0.71 mg/L before settling to a range of 0.87 to 0.33 mg/L after filtration. Iron ranged from 5.8 to 1.4 mg/L before settling and 0.59 to 0.39 mg/L after filtration.

Additional heavy metal analysis was performed for antimony, arsenic, beryllium, selenium, silver, and thallium. All metal concentrations remained below 0.09 percent and in a very narrow range as shown in

Table 18. Generally, they all meet the discharge limits to sewer. However, any strict requirement in some local regulations needs to be examined in the future.

Turbidity. Table 19 shows turbidity results for samples delivered to BTC environmental laboratory. There was a close relation between turbidity of the wastewater with its TSS. The highest turbidity was always exhibited for the wastewater piped directly from the ship boiler (S3).

Particle Size Measurement. Tables 21 and 22 show a definite advantage of the settling tank. The advantages of using filters for removing solids were less in this series of field tests than the first series.

Third Series of Field Tests

Test Set-up. This third series of field tests utilized the same set-up as the second series. The only difference was the use of three filters in series which were 50-, 25-, and 10-micron filters.

Test Operations. The hydroblast unit was started at 0815 on 24 June 1989. However, the diesel engine failed to maintain the proper 10,000 psig pump pressure. At 1330 of the same day, hydroblasting operations resumed. The cleaning operations were completed at 2230, 27 June 1989. For operational reasons, no shipyard work of any kind, including hydroblasting, was performed on the ship on Sunday 25 June. This series of tests to clean boiler 2B was completed with 12 recycles and represented a 92 percent reduction of wastewater.

Characteristics of Wastewater. The third series of field tests were done for boiler 2B. The characteristics of the wastewater are given in Tables 23 through 28. The turbidity and suspended solids are given in Table 29. The suspended solids from Tables 23 through 27 are also shown in Table 29. The particle size measurements are given in Tables 30 through 33. The following is the summary of the analytical data and results.

pH. The pH remained around 7.5 except for the first day's samples in Table 23 where the pH ranged from 9.18 for the fresh feedwater to 8.5 for the wastewater.

Oil and Grease. The first half of the data for oil and grease shows two samples concentrations of 94 and 100 mg/L and another four with a range of 13 to 19 mg/L. The remainder of the data shows concentrations of less than 5 mg/L.

Total Suspended Solids. Table 29 shows the results for total suspended solids performed by NNSY and the BTC Environmental Laboratory. Table 29 also includes the total suspended solids from Tables 23 through 27. Again, the results between the two laboratories are in good agreement. Generally, the larger the TSS was, the higher the turbidity of the wastewater. The last two sets of data show that the settling

TABLE 23

SAMPLE ANALYSIS FOR FIRST WASH
BOILER 2B, USS DAHLGREN AT 1405-6/24

Analysis for	Units	Sample Results S1-1405 6/24	S2-1405 6/24	S3-1405 6/24
pH		9.18	8.58	8.50
Oil and Grease	mg/1	13	9	18
Total Suspended Solids	mg/1	< 4.0	< 4.0	190
Total Dissolved Solids	mg/1	10	1200	1300
Nitrite	mg/1	< 1	970	1000
Nitrate	mg/1	< 1	4	4
<u>METALS</u>				
Cadmium	mg/1	< 0.002	<0.001	0.006
Chromium	mg/1	0.004	< 0.004	0.011
Copper	mg/1	0.13	0.013	15
Lead	mg/1	0.020	< 0.02	0.45
Mercury	mg/1	< 0.0002	< 0.0002	< 0.0002
Iron	mg/1	0.035	0.036	3.0
Nickel	mg/1	0.006	< 0.004	0.20
Sodium	mg/1	380	410	450
Zinc	mg/1	0.016	0.016	0.24

Remarks:

S1 - Clean Feedwater.

S2 - Clean Feedwater and sodium nitrite mixture.

S3 - Wastewater from boiler before settling tank.

TABLE 24

SAMPLE ANALYSIS FOR FIRST WASH
BOILER 2B, USS DAHLGREN, AT 1610-6/24

Analysis for	Units	Sample Results				
		S3-1610 6/24	S4-1610 6/24	S5-1610 6/24	S6-1610 6/24	S7-1610 6/24
pH		7.93	7.84	7.72	7.52	7.66
Oil and Grease	mg/1	94.0	18	6	19	9
Total Suspended Solids	mg/1	88	79	68	64	45
Total Dissolved Solids	mg/1	1000	860	950	950	950
Nitrite	mg/1	780	780	840	790	800
Nitrate	mg/1	4	4	4	5	4
METALS						
Cadmium	mg/1	0.010	0.008	0.007	0.006	0.008
Chromium	mg/1	0.039	0.015	0.007	0.011	0.025
Copper	mg/1	17	14	11	11	7.8
Lead	mg/1	0.74	0.60	0.52	0.49	0.47
Mercury	mg/1	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Iron	mg/1	5.48	1.7	1.4	1.4	1.2
Nickel	mg/1	0.30	0.20	0.16	0.14	0.12
Sodium	mg/1	1.5	360	310	360	360
Zinc	mg/1	0.33	0.26	0.22	0.25	0.18

Remarks:

S3 - Wastewater from boiler before settling tank.

S4 - Wastewater from boiler after settling tank.

S5 - Wastewater from boiler after 50 micron filter.

S6 - Wastewater from boiler after 25 micron filter.

S7 - Wastewater from boiler after 10 micron filter.

TABLE 25

SAMPLE ANALYSIS FOR FIRST WASH
BOILER 2B, USS DAHLGREN, AT 2300-6/24

Analysis for	Units	Sample Results				
		S3-2300 6/24	S4-2300 6/24	S5-2300 6/24	S6-2300 6/24	S7-2300 6/24
pH		7.46	7.02	7.05	7.15	7.26
Oil and Grease	mg/l	7	100	8	< 5	< 5
Total Suspended Solids	mg/l	55	67	50	30	24
Total Dissolved Solids	mg/l	940	910	940	940	960
Nitrite	mg/l	790	810	800	800	800
Nitrate	mg/l	4	4	4	4	4
METALS						
Cadmium	mg/l	0.008	0.005	< 0.002	< 0.002	< 0.002
Chromium	mg/l	0.006	0.017	0.017	0.011	0.024
Copper	mg/l	5.8	15	9.8	9.8	4.9
Lead	mg/l	0.29	0.64	0.48	0.31	0.35
Mercury	mg/l	< 0.0002	< 0.0002	< 0.0002	<0.0002	< 0.0002
Iron	mg/l	1.7	1.7	1.2	0.83	1.3
Nickel	mg/l	0.24	0.24	0.16	0.092	0.081
Sodium	mg/l	350	360	330	330	340
Zinc	mg/l	0.28	0.28	0.22	0.18	0.16

Remarks:

S3 - Wastewater from boiler before settling tank.

S4 - Wastewater from boiler after settling tank.

S5 - Wastewater from boiler after 50 micron filter.

S6 - Wastewater from boiler after 25 micron filter.

S7 - Wastewater from boiler after 10 micron filter.

TABLE 26

SAMPLE ANALYSIS FOR FIRST WASH
BOILER 2A, USS DAHLGREN, AT 1235-6/26

Analysis for	Units	Sample Results				
		S3-1235 6/26	S4-1235 6/26	S5-1235 6/26	S6-1235 6/26	S7-1235 6/26
pH		7.51	7.52	7.50	7.47	7.46
Oil and Grease	mg/1	< 5	< 5	< 5	< 5	< 5
Total Suspended Solids	mg/1	130	50	36	29	18
Total Dissolved Solids	mg/1	860	850	830	830	830
Nitrite	mg/1	750	740	750	760	740
Nitrate	mg/1	5	5	5	5	5
METALS						
Cadmium	mg/1	0.011	< 0.002	<0.002	< 0.002	0.004
Chromium	mg/1	0.027	0.011	0.012	0.010	0.010
Copper	mg/1	34	8.0	7.3	5.7	3.8
Lead	mg/1	0.93	0.39	0.40	0.29	0.20
Mercury	mg/1	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Iron	mg/1	2.8	0.94	0.85	0.73	0.55
Nickel	mg/1	0.44	0.14	0.13	0.082	0.073
Sodium	mg/1	310	330	330	300	350
Zinc	mg/1	0.36	0.20	0.18	0.15	0.14

Remarks:

S3 - Wastewater from boiler before settling tank.

S4 - Wastewater from boiler after settling tank.

S5 - Wastewater from boiler after 50 micron filter.

S6 - Wastewater from boiler after 25 micron filter.

S7 - Wastewater from boiler after 10 micron filter.

TABLE 27

SAMPLE ANALYSIS FOR FIRST WASH
BOILER 2B, USS DAHLGREN, AT 2230-6/26

Analysis for	Units	Sample Results				
		S3-2230 6/26	S4-2230 6/26	S5-2230 6/26	S6-2230 6/26	S7-2230 6/26
pH		7.54	7.49	7.53	7.51	7.49
Oil and Grease	mg/1	<5.0	<5.0	<5.0	< 5	<5.0
Total Suspended Solids	mg/1	74	34	60	28	17
Total Dissolved Solids	mg/1	870	840	840	1000	1000
Nitrite	mg/1	750	750	810	750	760
Nitrate	mg/1	5	5	5	5	5
METALS						
Cadmium	mg/1	0.011	< 0.002	< 0.002	< 0.002	0.002
Chromium	mg/1	0.038	0.012	0.012	0.008	0.009
Copper	mg/1	19	6.6	9.5	4.7	2.4
Lead	mg/1	0.60	0.36	0.51	0.21	0.11
Mercury	mg/1	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Iron	mg/1	5.6	0.76	0.91	0.54	0.46
Nickel	mg/1	0.35	0.13	0.21	0.092	0.079
Sodium	mg/1	340	320	320	330	330
Zinc	mg/1	0.35	0.18	0.22	0.15	0.11

Remarks:

S3 - Wastewater from boiler before settling tank.

S4 - Wastewater from boiler after settling tank.

S5 - Wastewater from boiler after 50 micron filter.

S6 - Wastewater from boiler after 25 micron filter.

S7 - Wastewater from boiler after 10 micron filter.

TABLE 28

ADDITIONAL HEAVY METAL ANALYSIS

FIRST WASH, BOILER 2B, USS DAHLGREN, AT NNSY

	Antimony	Arsenic	Beryllium	Selenium	Silver	Thallium
S2-1405 6/24	< 0.015	< 0.03	<0.001	< 0.04	< 0.002	< 0.04
S3-1610 6/24	0.033	< 0.03	<0.001	< 0.04	0.009	0.27
S7-1610 6/24	< .015	< 0.03	<0.001	< 0.04	0.004	0.15
S3-1235 6/26	0.047	< 0.03	<0.001	No data	0.012	0.30
S7-1235 6/26	0.029	< 0.03	<0.001	< 0.04	< 0.002	0.086
S3-2230 6/26	0.22	< 0.03	<0.001	< 0.04	0.04	0.27
S7-2230 6/26	0.026	< 0.03	<0.001	< 0.04	< 0.002	0.089

Remarks:

S2 - Clean Feedwater and sodium nitrite mixture.

S3 - Wastewater from boiler before settling tank.

S7 - Wastewater from boiler after 10 micron filter.

TABLE 29

TURBIDITY AND SUSPENDED SOLIDS FOR FIRST WASH
BOILER 2B, USS DAHLGREN, AT NNSY

Sample		Turbidity BTC NTU	Suspended Solids mg/l BTC[1]	Suspended Solids mg/l NNSY[2]
S1-1405	6/24	0.12	2	< 4
S2-1405	6/24	0.15	3	< 4
S3-1405	6/24	0.68	110	190
S3-1610	6/24	0.72	71	88
S4-1610	6/24	0.75	75	79
S5-1610	6/24	0.48	75	68
S6-1610	6/24	0.54	65	64
S7-1610	6/24	0.42	52	45
S3-2300	6/24	0.59	41	55
S4-2300	6/24	0.74	59	67
S5-2300	6/34	0.38	52	50
S6-2300	6/24	0.52	27	30
S7-2300	6/24	0.29	23	24
S3-1235	6/26	9.6	124	130
S4-1235	6/26	0.69	50	50
S5-1235	6/26	0.485	41	36
S6-1235	6/26	0.49	28	29
S7-1235	6/26	0.42	17	18
S3-2230	6/26	0.67	93	74
S4-2230	6/26	0.49	40	34
S5-2230	6/26	0.45	54	60
S6-2230	6/26	0.42	48	28
S7-2230	6/26	0.29	15	17

Remarks
1. Analysis Performed by BTC Environmental, Ventura, CA.
2. Analysis performed by Environmental Chemistry Laboratory, NNSY.

S1 - Clean Feedwater.
S2 - Clean Feedwater and sodium nitrite mixture.
S3 - Wastewater from boiler before settling tank.
S4 - Wastewater from boiler after settling tank.
S5 - Wastewater from boiler after 50 micron filter.
S6 - Wastewater from boiler after 25 micron filter.
S7 - Wastewater from boiler after 10 micron filter.

TABLE 30

PARTICLE SIZE MEASUREMENT FOR FIRST WASH
BOILER 2B, USS DAHLGREN, AT 1405-6/24

SIZE RANGE	SAMPLE S1-1405 6/24	CPPM	SAMPLE S2-1405 6/24	CPPM	SAMPLE S3-1405 6/24	CPPM
10 - 25μm	2,758	0.08	110,760	3.10	4,471,040	125.10
25 - 50μm	506	0.14	10,800	2.97	270,640	74.50
50 - 75μm	66	0.08	760	0.97	66,560	84.83
75 - 100μm	8	0.03	220	0.77	7,360	25.74
100 - 125μm	2	0.01	40	0.30	560	4.16
> 125μm	2	0.03	0	0.00	240	3.44
TOTAL	3,342	0.37	122,580	8.11	4,816,400	317.77

Remarks:

S1 - Clean Feedwater.

S2 - Clean Feedwater and sodium nitrite mixture.

S3 - Wastewater from boiler before settling tank.

TABLE 31

PARTICLE SIZE MEASURMENT FOR FIRST WASH
BOILER 2B, USS DAHLGREN, AT 1610-6/24

SIZE RANGE	SAMPLE S3-1610 6/24	CPPM	SAMPLE S4-1610 6/24	CPPM
10 - 25μm	3,147,680	88.07	8,511,120	238.14
25 - 50μm	89,440	24.62	163,280	44.95
50 - 75μm	2,560	3.26	1,360	1.73
75 - 100μm	160	0.56	0	0.00
100 - 125μm	80	0.59	0	0.00
> 125μm	0	0.00	0	0.00
TOTAL	3,239,920	117.10	8,675,760	284.82

SIZE RANGE	SAMPLE S5-1610 6/24	CPPM	SAMPLE S6-1610 6/24	CPPM	SAMPLE S7-1610 6/24	CPPM
10 - 25μm	2,572,800	71.99	4,960,160	138.79	4,593,320	128.52
25 - 50μm	59,100	16.27	44,640	12.29	63,640	17.24
50 - 75μm	560	0.71	5,520	7.04	520	0.66
75 - 100μm	60	0.21	160	0.56	0	0.00
100 - 125μm	0	0.00	0	0.00	0	0.00
> 125μm	0	0.00	0	0.00	0	0.00
TOTAL	2,632,520	89.18	5,010,480	158.68	4,656,480	146.42

Remarks:

S3 - Wastewater from boiler before settling tank.

S4 - Wastewater from boiler after settling tank.

S5 - Wastewater from boiler after 50 micron filter.

S6 - Wastewater from boiler after 25 micron filter.

S7 - Wastewater from boiler after 10 micron filter.

TABLE 32

PARTICLE SIZE MEASUREMENT FOR FIRST WASH
BOILER 2B, USS DAHLGREN, AT 1235-6/26

SIZE RANGE	SAMPLE S3-1235 6/26	CPPM	SAMPLE S4-1234 6/26	CPPM
10 - 25μm	8,714,800	243.84	3,871,320	108.32
25 - 50μm	341,600	94.04	100,640	27.71
50 - 75μm	16,100	20.52	1,280	1.63
75 - 100μm	4,200	14.69	40	0.14
100 - 125μm	100	0.74	0	0.00
> 125μm	100	1.43	0	0.00
TOTAL	9,076,900	375.26	3,973,280	137.80

SIZE RANGE	SAMPLE S5-1235 6/26	CPPM	SAMPLE S6-1235 6/26	CPPM	SAMPLE S7-1235 6/26	CPPM
10 - 25μm	2,888,640	80.82	2,632,920	73.67	1,147,680	32.11
25 - 50μm	20,440	5.63	43,160	11.88	20,200	5.56
50 - 75μm	160	0.20	200	0.25	320	0.41
75 - 100μm	0	0.00	40	0.14	0	0.00
100 - 125μm	0	0.00	120	0.89	40	0.30
> 125μm	0	0.00	40	0.57	0	0.00
TOTAL	2,909,240	86.65	2,676,480	87.40	1,168,240	38.38

Remarks:

S3 - Wastewater from boiler before settling tank.

S4 - Wastewater from boiler after settling tank.

S5 - Wastewater from boiler after 50 micron filter.

S6 - Wastewater from boiler after 25 micron filter.

S7 - Wastewater from boiler after 10 micron filter.

TABLE 33

PARTICLE SIZE MEASUREMENT FOR FIRST WASH
BOILER 2B, USS DAHLGREN, AT 2230-6/26

SIZE RANGE	SAMPLE S3-2230 6/26	CPPM	SAMPLE S4-2230 6/26	CPPM
10 - 25μm	2,516,680	70.42	4,496,240	125.80
25 - 50μm	71,600	19.71	82,880	22.82
50 - 75μm	5,160	6.58	1,120	1.43
75 - 100μm	160	0.56	0	0.00
100 - 125μm	0	0.00	0	0.00
> 125μm	0	0.00	0	0.00
TOTAL	2,593,600	97.27	4,580,240	150.05

SIZE RANGE	SAMPLE S5-2230 6/26	CPPM	SAMPLE S6-2230 6/26	CPPM	SAMPLE S7-2230 6/26	CPPM
10 - 25μm	4,077,200	114.08	3,681,200	103.00	1,147,300	32.10
25 - 50μm	110,480	30.41	123,200	33.92	39,020	10.74
50 - 75μm	1,000	1.27	1,400	1.78	2,120	2.70
75 - 100μm	0	0.00	320	1.12	120	0.42
100 - 125μm	0	0.00	160	1.19	0	0.00
> 125μm	0	0.00	40	0.57	40	0.57
TOTAL	4,188,680	145.76	3,806,320	141.58	1,188,600	46.53

Remarks:

S3 - Wastewater from boiler before settling tank.

S4 - Wastewater from boiler after settling tank.

S5 - Wastewater from boiler after 50 micron filter.

S6 - Wastewater from boiler after 25 micron filter.

S7 - Wastewater from boiler after 10 micron filter.

tank was advantageous. However, the preceding two sets of data show the settling tank having no effect, which might be due to turbulence caused by inadequate venting of the settling tank.

Total Dissolved Solids. Tables 23 through 27 show that the clean feed water (S1) had the lowest content of TDS. The feed solution (S2) had a significant increase in TDS due to the addition of sodium nitrite. The TDS of S3 through S7 remained in a range of 830 to 1300 mg/L, which indicates that the settling and filtration had no effect on the TDS.

Nitrite. Nitrite concentration remained in a narrow range of 750 to 840 mg/L, throughout the tests, which was very satisfactory.

Nitrate. Nitrate concentrations remained at 5 mg/L and below. That was also very satisfactory.

Heavy Metals. All the wastewater metal concentrations in Tables 23 through 28, except for iron and copper, were below 1 mg/L with the filtered wastewater having the least. Iron had a range of 5.6 to 1.7 mg/L before settling and a range of 1.3 to 0.46 mg/L after filtration. Copper had a range of 34 to 5.8 mg/L before settling and a range of 7.8 to 2.4 mg/L after filtration.

Additional heavy metal analysis was performed on antimony, arsenic, beryllium, selenium, silver, and thallium. All metal concentrations remained constant or remained below 0.09 percent in a very narrow range as shown in Table 28.

Turbidity. Table 29 shows the turbidity results for samples delivered to BTC Environmental Laboratory. There was a close relation between turbidity of the wastewater with its TSS. The highest turbidity was always exhibited in wastewater taken directly from the ship boiler (S3).

Particle Size Measurement. Tables 30 through 33 show the results of the particle size measurement on selected sample sets. Certain data show that subsequent to settling and filtration, the particle count for the 10 - 25 micron size increases. Several plausible explanations are offered for this abnormality: first, an analytical error is possible. However, discussions with the analytical personnel revealed that such error is unlikely since the corresponding TSS data shows a similar increase. Second, a turbulence or disturbance in the settling tank is very likely due to the inadequate venting. As mentioned before, turbulence in the settling tank will increase the downstream suspended solids concentration and the smaller particles will be the most affected. Third, the increase in the fine (10 - 25-micron) particles might also be caused by these particles being shaken loose due to pressure pulses as the recycling pump was switched off and on.

Overall Results and Considerations

The summarized results and some considerations for all three series of field tests are given below:

pH. The pH of the hydroblasting wastewater throughout the three series of tests remained generally in a range of between 7 and 8. This pH range meets regulations on wastewater discharge.

Oil and Grease. The oil and grease in the wastewater show overwhelmingly less than 5 mg/L. Seven samples out of a total of 42 had over 10 mg/L with three samples out of the seven being between 90 - 100 mg/L. It should be noted that these high levels were from the same sample set. The NNSY chemical laboratory checked all their procedures and calculations and discovered no mistakes. Their explanation for these samples with the high oil and grease content is that oil and grease from the sample taker's glove got into the sample bottle. Thus, there is no apparent increase of oil and grease during the hydroblasting operations. Also, there is no need of oil pretreatment for the recycled wastewater.

Total Suspended Solids. Tables 8, 19, and 29 show the results for the TSS concentrations for the first and second wash of boiler 1A and the first wash of boiler 2B. Two separate samples from each sample port were taken concurrently and analysis performed at two independent laboratories. Generally the tables show a good agreement in the results.

However, the above tables contain certain inconsistencies. Samples taken at 1830 (first series Table 8) and samples taken at 2300 (third series Table 29) show a higher TSS content after settling than before settling. This trend is exhibited in both sets of samples taken concurrently but analyzed by separate laboratories. The one plausible reason would be some kind of turbulence of the settled particulates. This is not unusual given the many activities of other heavy equipment along the pier. Furthermore, the 600-gallon settling tank did have inadequate venting that might result in back pressure and turbulence when the wastewater level in the tank was high.

Table 34 gives the "Before Settling" and "After Last Filtration" TSS data for the three series of field tests in a high/low range. The table shows the same high/low ranges, with and without both extreme values discarded. The discarded high or low values are considered to be erratic data points and not truly representative. It is important to note that almost all the suspended solid particles larger than 75 microns were completely removed after filtration. It should also be pointed out that the TTS discharge limit is seldom enforced. However, a few local governments do restrict TTS at 60 ppm in the wastewater to discharge to a sewer or sanitation plant. Our data show that the hydrobasting wastewater generally exceeds this discharge limit before settling and filtering.

Total Dissolved Solids. The clean feed water TDS content (S1) ranged from a high of 120 mg/L for the first series test to a low of 10 mg/L for the last series test. The feed solution TDS content (S2) was significantly higher due to the addition of sodium nitrite. The range was between 800 to 2000 mg/L but predominantly around 1200 mg/L. The wastewater TDS content at all sample ports was similar to or higher than that of the feed solution (S2).

Table 34

Summary of Total Suspended Solids (Mg/L)

Field Test Series	Before Settling	After Last Filtration
1st Series, 1st Wash Boiler 1A	204 - 9 (200 - 41)	38 - 4 (35 - 5)
2nd Series, 2nd Wash Boiler 1A	383 - 13 (44 - 21)	25 - 0.01 (20 - 6)
3rd Series, 1st Wash Boiler 2B	190 - 41 (130 - 55)	52 - 15 (45 - 17)

Note: Values in brackets are the data after discarding a few extreme high and low points.

Nitrite. The results indicate that for the first and third series of tests, the nitrite concentration ranged below the required 800 mg/L. Results for the second series of tests show a higher than proper concentration range. However, for all the tests, the nitrite concentration remained in a constant range with no loss.

Nitrate. Generally the nitrate concentration was below 10 mg/L. There was no nitrite conversion to nitrate. This simplifies the suggested reconditioning step of the recycling process. For the future standard procedure, we only need to use simple method to check the nitrite, such as the Hach calorimetric method.

Heavy Metals. Tables 18 and 28 show the analyses of those heavy metals which belong to the EPA priority pollutants, but usually are not required to be monitored in local regulations. These two tables indicate that arsenic, beryllium, selenium, and silver had no change in concentrations from fresh feed solution to recycled wastewater. Table 35 summarizes the total metals concentrations in a high/low format for all the three tests combined. The results are given for "fresh feed solution," "before settling," and "after last filtration." Meanwhile, the discharge limits to the sewer are listed for reference. Again, the results in brackets are the representative ranges after discarding a few extreme high and low data points. Table 35 shows that cadmium and chromium had the least average percentage increase while copper had the highest (400 fold) increase from "fresh feed solution." Furthermore, all heavy metal concentrations were significantly reduced after their last filtration as compared to the wastewater from the ship boiler (S3). It is also interesting to note that only copper and lead exceeded the discharge limits to sewer after last filtration (25- or 10-micron filter). In our overall technical approach, the final recycled wastewater, which will be about 10 percent of the total hydroblasting wastewater, will be treated for disposal in a separate R&D project.

Turbidity. Tables 8, 19, and 29 show the turbidity results performed on the wastewater for the first, second, and third series of tests. The analysis was performed on samples delivered to BTC Laboratory. The results do show that turbidity is increased by the increasing of suspended solids.

Particle Size Measurement. Tables 9 - 12, 20 - 22, and 30 - 33 represent the data of the particle size measurements performed on selected samples for the the first, second, and third series of tests. Generally these data show an overwhelming trend of particle reductions in size and quantity of the wastewater after settling and filtration. However, certain results are inconsistent as evidenced in an increase in the size and count of particles after settling and successive filtering. The cloth filters are rated at 50 percent efficiency to remove the particles equivalent to the given size of filter. As the recycling process continues, particles accumulating on the filter increased. Also, during the recycling mode, the recycling pump is continually turned on and off to maintain the proper level in the 65 gallon feed solution tank of the hydroblast unit. It is therefore conceivable that

TABLE 35

Total Metal Concentrations mg/L

	Fresh Feed Solution	Before Settling	After Last Filteration	Discharge Limit
Cadmium	.003 - <.001	.022 - <.001	.01 - .001	0.10
Chromium	.01 - <.004	.087 - <.002	.035 - .009	0.05
Copper	.014 - .011	54 - 0.71 (34 - 1.1)	7.8 - 0.33 (6.98 - 0.65)	2.00
Lead	<.02 - .01	1.06 - 0.036 (0.93 - 0.088)	0.86 - 0.075 (0.50 - 0.11)	0.05
Iron	0.13 - 0.036	10.1 - .028 (5.8 - 1.4)	2.03 - 0.39 (1.3 - 0.41)	No req'd limit
Nickel	<.004 - <.003	0.44 - 0.006 (0.35 - 0.022)	0.12 - 0.01 (.081 - 0.022)	0.40
Zinc	.053 - .016	0.51 - .09 (0.46 - 0.24)	0.37 - 0.11 (0.24 - 0.13)	1.48
Antimony	.015	.22 - .019 (.054 - 0.033)	.31 - 0.015 (.029 - .018)	1.00
Thallium	<.04	0.30 - 0.054 (0.27 - 0.093)	0.15 - <0.04 (0.039 - 0.04)	-

(1) Values in brackets are likely representative ranges after discarding a few extremely high and low data points.

(2) The discharge limits are the most stringent requirement to sewer or sanitary plants in Philadelphia, PA, Los Angeles, and Sunnyvale, CA. Also, these discharge limits are applicable to the Industrial Waste Treatment Plant at Norfolk Naval Shipyard, VA., and Pearl Harbor Naval Shipyard.

with the pressure surges of the recycling pump, some particulates are dislodged from the filters back into the wastewater stream and into sample bottles. Consequently, the analysis showed inconsistent results.

Table 36 is a summary of the total suspended solids count for potable water, fresh feed solution, wastewater before settling, and wastewater after last filtration for all three series of tests. All samples show a significant drop in the total particle count through settling and filtration except one taken at 1610, June 24, 1989.

Table 37 is a summary of the particle counts of the small particle size (10 - 25 microns) and the large particle size (above 75 microns). It can be seen that the particle numbers of both categories increased from potable water, to feed solution, and to wastewater. Then the particles were reduced after settling and filtering.

SAFETY

Safety Procedures for Field Tests and Operations

Safety During Recycling of Hydroblasting Wastewater. Detailed test and safety procedures for recycling of hydroblasting wastewater have been prepared by NCEL. These procedures were used during three series of field tests in FY89 and the forthcoming implementation tests. As shown in the Appendix, the procedures consist of two sections. One is an operational test procedure. The other is a task hazard analysis.

Safety During Hydroblast Washing. Naval shipyards have standard equipment and safety procedures for operation of their hydroblast units. During hydroblast washing of ship boilers, each shift consists of four persons: foreman, unit operator, gun operator, and lance operator. The unit operator is stationed at the engine side of the hydroblast unit and operates its engine. The gun operator is stationed outside the boiler's steam drum and operates control gun on the voice instruction from lance operator. The lance operator is stationed inside the steam drum and handles lance to wash boiler tubes and drums. The lance operator must wear a rain suit and nonvented chemical gloves, put on his face shield, and if necessary use a respirator connected to an air canister. A hard hat, goggles, and ear plugs are recommended for other operators performing the hydroblast work. With these protective clothing and accessories, the operators are fully shielded from potentially hazardous solution and wastewater.

Safety Procedures for Personnel Health

Toxicity Tests. In order to determine whether the hydroblasting wastewater is toxic, various samples of both first washing and second washing were analyzed by the BTC Environmental Laboratory, Ventura, CA.

Briefly, the method is a 96-hour toxicity test using 10 small fish (fathead minnows) to determine the LC_{50} (lethal concentration, 50 percent). In addition to a control sample using pure water, two concentrations of wastewater are prepared: one with 250 mg of wastewater diluted to one liter, and the other with 750 mg of wastewater diluted to one liter. The fathead minnows are placed into the control sample and the diluted

Table 36

Summary of Total Suspended Soilds Count
(10 micron and over Per 100 mL wastewater)

Sample	1st Series Tests	2nd Series Tests	3rd Series Tests
S1: Potable water	14,736	32,048	3,342
S2: Fresh feed solution	48,936	46,384	122,580
S3: Before settling	10,631,920	4,270,200	4,816,400

Wastewater before settling	5,968,980	5,098,160	3,239,920
Wastewater after last filtration	255,320	1,194,800	4,656,480

Above samples taken at 1045-4/26, 1615-6/26, and 1610-6/24 for 1st, 2nd, and 3rd series respectively.

Wastewater before settling	4,299,440	5,355,680	8,714,800
Wastewater after last filtration	3,810,336	1,672,800	1,168,240

Above samples taken at 1830-4/26, 0700-6/27, and 1235-6/26 for 1st, 2nd, and 3rd series respectively.

Wastewater before settling	9,999,720	-	2,516,680
Wastewater after last filtration	956,912	-	1,188,600

Above samples taken at 0245-4/27 and 2230-6/26 for 1st and 2nd series respectively.

Table 37

COMPARATIVE PARTICLE COUNT FOR MICRON SIZES OF 10-25 AND OVER 75

Type of water	1st Series		2nd Series		3rd Series	
	10-25μ	>75μ	10-25μ	>75μ	10-25μ	>75μ
Potable Water	12,500	65	27,500	136	3,000	12
Feed Solution	46,000	428	30,000	344	111,000	260
Wastewater before settling	$(4.2-10.5)*10^6$	300-8000	$(3.5-5.2)*10^6$	160-7000	$(2.5-8.7)*10^6$	160-8000
Wastewater after last filter	$(200-3700)*10^3$	250-4000	$(1.1-1.6)*10^6$	80-320	$(1.1-4.6)*10^6$	0-160

wastewater samples. Keep the samples at pH around 7, temperature at 25 °C, and dissolved oxygen at 6-7 ppm (by aeration), and count the number of the fathead minnows killed at 24, 48, 72, and 96 hours. If a total of 50 percent of the fathead minnows (5 in this case) are killed within 96 hours at 250 mg/L wastewater, the LC_{50} is 250 mg/L. According to the regulations of the State of California, a water stream is considered to be toxic when its LC_{50} is 500 mg/L. It should be noted that the control sample is used to check whether the fathead minnows are healthy or not. If more than 10 percent (one fish) dies in the control sample, the pure water used to prepare the dilute wastewater has been contaminated and should be changed.

Table 38 shows the toxicity test results of the feed solution and wastewaters from second hydroblast washing of a ship boiler. The results indicate that feed solution (S2) caused one fathead minnow to die, but the highest mortality was only 2 dead at 750 mg/L wastewater (S3) of 21 June 1990 sample. Thus, the feed solution, the wastewater from the boiler, and the wastewater after settling and filtering (S6) were all not toxic. Furthermore, the recycled wastewater (S6) did not increase the toxicity over the feed solution (S2). Similar results were obtained in Table 39. It shows that the wastewater from first hydroblast washing of another boiler was not toxic either.

It is interesting to note that the hydroblasting wastewater is still considered to be hazardous due to nitrite, heavy metals, and suspended solids. Many state and local governments restrict the discharge of hydroblasting wastewater into a sewer system or sanitation plant.

Health Effect. It is important to analyze for heavy metals in the wastewater which may adversely affect workers' health. As shown in Table 35, concentrations of the heavy metals are very low.

The ability of a substance to cause damage to human beings is through ingestion, inhalation, and absorption on the skin. The damage depends on concentration of the substance and time of the human exposure to it. When the operators involved in the hydroblasting and recycling operations wear protective clothes and accessories and follow the safety procedures given in above sections, the operations should not result in any health problems. Furthermore, the vapor pressures of the heavy metals in the hydroblasting wastewater are so low that the operators could not inhale enough to cause damage. If necessary, the operators can take more frequent breaks. It is customary for operators to take a short break after 3 - 4 hours of operation. Also, the jobs among the unit operator, gun operator, and lance operator have been rotated during each 12-hour shift. Consequently, the exposure of each lance operator to hot water moisture inside the boiler is decreased to a minimum.

Detailed information on materials of a hazardous nature and personal protection of the chemicals involved in hydroblasting wastewater can be found from material safety data sheets (MSDS). The MSDS are available from the chemical producers and/or safety offices in Naval Shipyards.

Table 38

Toxicity Test

For Second Wash, Boiler-1A, USS DAHLGREN

	Sample	Mortality		
		Control	250 mg/L	750 mg/L
24 hours	S2-2115-6/20	0	0	0
	S3-2115-6/20	0	1	1
	S3-2015-6/21	0	0	0
	S6-2015-6/21	1	0	0
48 hours	S2-2115-6/20	0	0	0
	S3-2115-6/20	0	0	0
	S3-2015-6/21	1	0	1
	S6-2015-6/21	0	0	0
72 hours	S2-2115-6/20	0	0	0
	S3-2115-6/20	0	0	0
	S3-2015-6/21	0	0	0
	S6-2015-6/21	0	0	0
96 hours	S2-2115-6/20	0	1	0
	S3-2115-6/20	0	0	0
	S3-2115-6/21	0	0	1
	S6-2015-6/21	0	0	0
Total	S2-2115-6/20	0	1	0
	S3-2115-6/20	0	1	1
	S3-2115-6/21	1	0	2
	S6-2015-6/21	1	0	0

S2 - Fresh feedwater solution with sodium nitrite mixture.
S3 - Wastewater before settling and filtration.
S6 - Wastewater after settling and filtration.

Table 39

Toxicity Test

For First Wash, Boiler 2-B, USS DAHLGREN

	Sample	Mortality		
		Control	250 mg/L	750 mg/L
24 hours	S2-1405-6/24	0	0	0
	S3-1405-6/24	0	0	0
	S3-1235-6/26	1	0	0
	S7-1235-6/26	0	0	0
48 hours	S2-1405-6/24	0	0	0
	S3-1405-6/24	1	0	0
	S3-1235-6/26	0	0	0
	S7-1235-6/26	0	0	0
72 hours	S2-1405-6/24	0	0	0
	S3-1405-6/24	0	0	0
	S3-1235-6/26	0	0	0
	S7-1235-6/26	0	0	0
96 hours	S2-1405-6/24	0	0	1
	S3-1405-6/24	0	0	0
	S3-1235-6/26	0	0	0
	S7-1235-6/26	0	0	0
Total	S2-1405-6/24	0	0	1
	S3-1405-6/24	1	0	0
	S3-1235-6/26	1	0	0
	S7-1235-6/26	0	0	0

S2 - Fresh feedwater solution with sodium nitrite.
S3 - Wastewater before settling and filtration.
S7 - Wastewater after settling and 10 micron filter.

ECONOMICS

Background of Disposal Cost for Hazardous Wastewater

There are often various disposal costs reported for same type of hazardous wastewater (HWW). The variation in cost at different Navy activities may arise from one or more of the following: (a) An activity transports its HWW to another Navy activity for treatment; the former considers only the transport expense as its disposal cost. (2) An activity uses its existing facilities, such as IWIP, to treat an added HWW, and it considers only the cost of the required chemicals for treatment as the disposal cost of this added HWW. (3) An activity requests DRMO to have contractors to dispose of its HWW. Some contractors perform appropriate pretreatment prior to discharge, while other contractors do not. (4) An activity that may not be aware of the hazardous nature of a waste stream discharges directly to a sewer or receiving water. (5) Some state and local governments have stricter discharge limits than others.

Currently there are different disposal costs for the water-jetting (hydroblasting) wastewater. It should be noted that hydroblasting wastewater is the main source of sodium nitrite wastewater which, in turn, is the major stream of a ship's bilge wastewater. The bilge wastewater is a conglomerate which contains heavy metals, oil, grease, suspended solids and other toxic substances. This combined wastewater resists available treatment method. During our site visit at Philadelphia NSY in June, 1990, the computer print-out sheets showed that the contractor's disposal cost for the bilge wastewater was $6.00 per gallon when the contractor determined the wastewater to be toxic, or $3.00 per gallon when the contractor determined the wastewater to be only corrosive. During our site visit at Long Beach NSY in February, 1988, the bilge wastewater was transported to Navy IWIP at San Diego. The transport expense of $0.11 per gallon was quoted as the disposal cost. However, the Navy IWIP at San Diego stopped accepting the hazardous wastewater from Long Beach NSY in 1990. Consequently, the average disposal cost of the bilge wastewater through DRMO in the nine months from January through September 1990 was $2.25 per gallon.

Recently, the Naval Surface Force, U.S. Atlantic Fleet (Ref 3), quoted a price of $0.50 a gallon for treatment of the sodium nitrite wastewater at Public Works Center (PWC) Norfolk. It is also the highest price routinely used by COMNAVSURFLANT activities. Reference 3 further indicates that there was no disposal/treatment cost associated with sodium nitrite wastewater at PWC Mayport.

We know that sodium nitrite wastewater is a HWW. Many local governments restrict the nitrite content to be discharged to sewer or sanitation plant to 33 ppm (mg/L). The nitrite content in our sodium nitrite wastewater is around 800 ppm. When a Navy activity discharges the sodium nitrite wastewater without disposal/treatment cost, apparently this HWW has been discharged without treatment. Sooner or later that activity will be liable for the consequences.

We also know that most shore intermediate maintenance activities (SIMA's) have not separated the hydroblasting wastewater from other bilge wastes. Their current practice is to pump out the mixed waste from ship and store in a donut. Usually the bilge and donut have already had various solvents, oils, greases, and heavy metals. The combined wastestream easily becomes very toxic. Many local governments and environmentalists have already had strong objection to the Navy's donuts in harbors because very often the toxic wastes leak into the harbors.

Currently, only Norfolk NSY can convert the sodium nitrite to non-toxic components. We are not aware of any other shipyard, SIMA, or contractor knowing how to destroy sodium nitrite followed by removal of heavy metals and suspended solids. (NCEL is developing such an integral process.)

We know that several Navy activities are going to replace sodium nitrite with EDTA/hydrazine. We would like to offer a word of caution here. EDTA stands for ethylenediamine tetraacetic acid. It is a colorless crystalline organic chelating agent. EDTA binds to heavy metals and makes them soluble. Chelated heavy metals cannot be removed by precipitation by adjusting pH, which is the standard practice in the Navy IWIP. In addition, hydrazine is highly toxic by ingestion, inhalation, and skin absorption. Its tolerance in air is 1 ppm. The discharge limit of total toxic organics in wastewater is 2.13 ppm set by EPA. Thus, the substitution of these two chemicals may result in adverse health effects for the water-jetting operators and a higher disposal cost for the wastewater.

After considering all the facts and data, we decided to use $3.25 per gallon as an initial estimate for the disposal and associated logistics cost for hydroblasting wastewater mixed with bilge wastewater. During the recycling tests, NCEL and certain Naval Shipyards initiated the separation of hydroblasting wastewater from other bilge wastes. The remaining hydroblasting wastewater (10 percent) after recycling will be combined with two other sources of sodium nitrite wastewater and treated. One source is from boiler lay-up and the other is from boiler hydrostatic pressure testing. These two streams are separated from other bilge wastes. This combined sodium nitrite wastewater is less contaminated than the previous combined bilge wastewater; for this reason, we decided to set the cost of disposal at $2.00 per gallon for these conditions.

Savings of Wastewater Disposal Cost at Naval Shipyards

There are about 25 ships overhauled annually at Naval Shipyards. Each ship has an average of four boilers. Each medium size boiler has 1,700 tubes, which consume about 14,000 gallons of fresh feed solutions for one hydroblast washing. Usually two washes are done in the overhauling period. The wastewater produced is:

$$\frac{25 \text{ ships}}{\text{yr}} \times \frac{4 \text{ boilers}}{\text{ship}} \times \frac{2 \text{ washes}}{\text{boiler}} \times \frac{14{,}000 \text{ gal}}{\text{wash}} = 2{,}800{,}000 \text{ gal/yr}$$

As stated above, before NCEL started research and development on recycling in FY88 (October 1987), the hydroblasting wastewater had been mixed with other bilge wastes. The unit disposal cost by contractor hauling was about $3.25/gal and the total disposal cost was approximately $9 million/yr. After a reduction of 90 percent of the hydroblasting wastewater by recycling technique, only the remaining 10 percent is needed to be disposed of or hauled away. Since this remaining wastewater has been separated from other bilge wastes, its disposal and associated logistic cost should be cheaper, about \$2.00/gal. Therefore, the saving in wastewater disposal cost is approximately \$8 million/yr as follows:

$$2{,}800{,}000\ \frac{\text{gal}}{\text{yr}} \times \frac{\$3.25}{\text{gal}} - 280{,}000\ \frac{\text{gal}}{\text{yr}} \times \frac{\$2.00}{\text{gal}} \cong \$8 \text{ million/yr}$$

Savings on Wastewater Disposal Cost Beyond Naval Shipyards

There are 150-200 Navy ships whose boilers are cleaned once annually with hydroblast washing outside Naval Shipyards. The cleaning operations are done by Shore Intermediate Maintenance Activities, tenders, and ship onboard hydroblast units. Total wastewater produced is:

$$\frac{175 \text{ ships}}{\text{yr}} \times \frac{4 \text{ boilers}}{\text{ship}} \times \frac{1 \text{ wash}}{\text{boiler}} \times \frac{14{,}000 \text{ gal}}{\text{wash}} = 9{,}800{,}000 \text{ gal/yr}$$

If the NCEL developed recycling technology is adopted to all ships in these instances, a savings around \$30 million/yr can be realized:

$$9{,}800{,}000\ \frac{\text{gal}}{\text{yr}} \times \frac{\$3.25}{\text{gal}} - 980{,}000\ \frac{\text{gal}}{\text{yr}} \times \frac{\$2.00}{\text{gal}} \cong \$30 \text{ million/yr}$$

Life Cycle Economics

This economic evaluation includes capital cost and operating cost of the recycling process. These costs are expressed in terms of present value cost (PVC) and savings at 10 percent annual discount rate over a 10-year life of the mobile recycling unit.

Capital Cost. Basis:

1. 250 steam boilers are to be cleaned with hydroblast once a year.

2. Each boiler wash (cleaning) generates 14,000 gallons of wastewater.

3. 50 mobile recycle units will be constructed.

It should be noted that although each recycling unit will be used to do only five washes annually, at least 50 units are needed to station strategically at different locations to meet the Navy-wide operations. The capital cost of one recycling unit is as follows:

One two-axle four-wheel trailer (6 tons)	$3,800.00
Two 600-gal high-density polyethylene settling tanks	2,500.00
One copper-nickel shell tube heat exchanger	2,500.00
Three type 304 stainless steel filter housings	1,500.00
Three cartridge filter housings	500.00
One electric impeller pump	500.00
Two flow totalizers	300.00
Flow switches, flow meters, relays, and nitrite monitor	700.00
Pressure gauges, temp. indicators, valves, and filters	700.00
Subtotal	13,000.00
Installation (factor = 50%)	6,500.00
Contingency (factor = 10%)	1,300.00
Total	$20,800.00

Total capital cost of 50 recycling units = $1,040,000 = $1,040K

Operating Cost. Basis:

1. Unit labor cost = $36/man-hour.

2. Labor required for one boiler wash = 5 man-hours.

It should be noted that the effort to operate a recycling unit is only to turn two valves on and off and change filters, then clean the two settling tanks at the end of hydroblast washing. It can be accomplished with a total of 5 hours work by the hydroblast unit operator during one boiler cleaning operation. The operating cost is as follows:

Labor cost (5 man-hours)	$180.00
Maintenance	100.00
Utilities (electricity and cooling water)	40.00
Subtotal	$320.00

The annual operating cost to recycle the hydroblasting wastewater from 250 washes is:

$$\frac{250 \text{ washes}}{\text{yr}} \times \frac{\$320}{\text{wash}} = \$80\text{K}$$

The cumulative discount factor (CDF) at 10 percent discount rate for a 10-yr period is 6.447, hence the present value cost (PVC) of a 10-yr period is:

80K x 6.447 = $516K

The total PVC in a 10-yr economic life is:

capital cost + operating cost: 1,040K + 516K = $1,556K

Life Cycle Savings. Basis: (1) hydroblasting wastewater reduction = 90 percent, and (2) unit disposal cost without recycling = $3.25/gal. The annual disposal cost of wastewater produced from 250 washes is:

$$\frac{250 \text{ washes}}{\text{yr}} \times \frac{14{,}000 \text{ gal}}{\text{wash}} \times \frac{\$3.25}{\text{gal}} = \$11{,}375\text{K/yr}$$

PV of the disposal cost reduction at 90 percent wastewater reduction is:

11,375K x 0.9 x 6.447 = $66,000K

∴ PV savings in a 10-yr life is:

66,000K - 1,556K = $64.4 million

CONCLUSIONS

Based on the data and results of the three series of field tests as well as safety procedures and economics analysis, we reached the following conclusions:

1. Three series of field tests were successfully conducted at Norfolk Naval Shipyard. These tests resulted in 75, 90, and 92 percent reductions of hydroblasting wastewater respectively. A 90 percent reduction by 9 recycles was found to give optimum boiler tube cleaning results.

2. The recycling process consists of wastewater collecting, settling, filtering, reconditioning, and reuse.

3. The pH remained in a narrow range of 7.1 to 8.7 in fresh feed solution and various stages of wastewater during recycling. This pH range meets discharge limits to the sewer or public owned treatment plant.

4. Oil and grease remained well below 100 mg/L. Consequently, no pretreatment of oil and grease to the boiler wastewater is needed for the recycling process.

5. The suspended solid particles larger than 75 microns were almost completely removed from wastewater after settling and filtering.

6. Sodium nitrite, a corrosion inhibitor, was not decreased during recycling. Also, the nitrite was not oxidized to nitrate. This finding simplified the reconditioning step, which was intended to replenish the sodium nitrite concentration.

7. Most heavy metals in the boiler wastewater were significantly reduced through settling and filtration. It appears that only copper and lead in the final recycled wastewater exceeded the discharge limits to a sewer or public owned treatment plant.

8. Detailed test and safety procedures for recycling of hydroblasting wastewater have been prepared. These procedures were used in the three series of field tests and will be augmented for future implementation tests.

9. The fresh feed solution and hydroblasting wastewaters at various stages (from boiler, settlement, and filtration) were examined using standard 96-hour toxicity tests and found to be nontoxic. However, the wastewaters are classified as hazardous due to sodium nitrite, heavy metals, and suspended solids.

10. There are 2.8 million gal/yr of hydroblasting wastewater produced at Naval Shipyards. The hydroblasting wastewater had been mixed with bilge wastes before NCEL started R&D work in 1987 resulting in a disposal cost of about $3.25/gal. After a 90 percent reduction of the wastewater using the recycling technology, the remaining 10 percent, segregated from other bilge wastes, will be disposed with two other boiler (sodium nitrite) waste streams at a cost of about $2.0/gal. Consequently, the total savings in wastewater disposal costs at Naval Shipyards would be approximately $8 million/yr.

11. There are 9.8 million gal/yr of hydroblasting wastewater produced at Navy facilities outside Naval Shipyards for Navy ships. If NCEL's recycling technology is adapted to all such ships, an additional savings on wastewater disposal cost of approximately $30 million/yr can be realized.

12. An economic evaluation of the recycling process is also made for the 10-yr life cycle. It is intended to conduct 250 boiler washes annually using 50 mobile recycling units. The present value saving at a 10 percent discount rate is $64 million for the 10-yr economic life.

RECOMMENDATIONS

The following additional work is recommended:

1. Design and construct a mobile recycling unit to encompass all the components used in the three series of field tests. A mobile unit can extend the usefulness and applications of the recycling technology more widely and economically.*

2. Conduct an implementation test, with the above mobile recycling unit at a Naval Shipyard. The implementation test should be done jointly with NAVSSES, NEESA, and the shipyards which have a Navy ship requiring hydroblast cleaning of steam boilers.*

3. Prepare User's Data Package (UDP). It should not only follow NAVFAC guidelines but also meet NAVSSES requirements.

REFERENCES

1. Naval Civil Engineering Laboratory. Memorandum to files on the initial feasibility study on recycling of hydroblasting wastewater, by Bingham Y.K. Pan, Port Hueneme, CA, Feb 1989.

2. Naval Sea Systems Command. Naval Ships' Technical Manual, S9086-GY-STM-010, Chapter 221, First Revision, Oct 1987, Philadelphia, PA.

3. Naval Surface Force, U.S. Atlantic Fleet ltr 4700 Ser N42/01567 of 4 Feb 1991.

NOMENCLATURE

CDF	Cumulative discount factor
DRMO	Defense Reutilization and Marketing Office
EPA	Environmental Protection Agency
gpm	Gallons per minute
HWW	Hazardous wastewater

*Three mobile recycling units have been designed and constructed with an enhanced 2-tank settling design and automated water delivery by NCEL in 1990. The technology transfer and implementation tests will be included in the forthcoming UDP.

LBNSY	Long Beach Naval Shipyard
mg/L	Milligram per liter
ml	Milliliter
MSDS	Material Safety Data Sheet
NAVSSES	Naval Ship Systems Engineering Station
NCEL	Naval Civil Engineering Laboratory
NEESA	Naval Energy and Environmental Support Activity
NNSY	Norfolk Naval Shipyard
PVC	Present value cost
PWC	Public Works Center
SIMA	Shore Intermediate Maintenance Activity
TDS	Total dissolved solids
TSS	Total suspended solids
UDP	User's Data Package

Appendix

TEST AND SAFETY PROCEDURES FOR RECYCLING OF HYDROBLASTING WASTEWATER EXPERIMENTS AT NAVY SHIPYARDS*

April 1989 - September 1990

by

Raymond J. Cappillino

Brian E. Swaidan

Naval Civil Engineering Laboratory
Port Hueneme, CA 93043

*The test and safety procedures were approved by NCEL safety officer.

DESCRIPTION OF EXPERIMENT

This recycling experiment will be conducted aboard a ship or pier. The purpose is to evaluate the reduction of hydroblasting wastewater using recycling technique during hydroblast cleaning operations. The hydroblasting (water jetting) operations remove soft scale and debris from internal boiler surfaces with 1 pound sodium-nitrite in 100 gallons of potable water that is pressurized to 10,000 psi and directed against the tube surface through specially designed nozzles. The wastewater resulting from this operation (because of the sodium nitrite, suspended solids, and heavy metals) must be disposed of as hazardous material. The development of an acceptable recycling process is needed to significantly reduce the volume of the wastewater.

To carry out these experiments, the hydroblasting wastewater will be collected separately and accumulated in a 600- to 2500-gallon settling tank. The wastewater is then pumped through a filter assembly, replenished with sodium nitrite if necessary, and sent back into the ship's boiler via the hydroblast unit. Pressure and fluid flow measurements will be recorded, freshwater and wastewater samples will be collected for analysis, and solid samples will be taken from the filter for analysis. Expected duration of each test will be 36 to 60 hours, barring unforeseen delays and interruptions in boiler cleaning operations.

OPERATIONAL TEST PROCEDURE

Pre-Test Operations

1. Assemble test apparatus including filter assemblies, valves, pressure gauge, etc.

2. Assemble the following safety items for use at the test site:

   a. Hard hats

   b. Safety goggles, safety glasses, and ear plugs

   c. Rubber mat for base of electric motor

   d. Neoprene coated gloves

   e. Safety shoes

   f. Work gloves

3. Assemble and transport the following supplies and equipment to the test site:

   a. Test fixture

   b. Primary and alternate pumps

c. Ice chest and sample bottles for water samples

d. Replacement filters

e. 50-ft electrical extension cord and pump switch

f. Camera (pass required)

g. Zip-lock bags for used filters

h. Small tool chest and tool-carrying bag

i. Bucket for pump priming

Site Set-up Operations

1. The on-site supervisor shall survey the site and conduct a safety meeting covering on-site safety with all the personnel involved. Items of discussion shall include vehicular traffic, cranes, and other operating equipment, any other potential safety hazard and standard operating procedures in case of any emergencies.

2. Arrive one day early to set-up and check out system for proper operation. If possible, use an out-of-the-way space in the boiler room or on the pier (will depend on working/crowding conditions) but as close to the wastewater supply as possible.

3. Determine ship, shipyard and/or station procedures for emergency situations; then determine what response will be for those situations. Record these procedures and instructions on final page of these instructions.

4. Secure a source of freshwater in the proximity of the test site. Have available a minimum 50 foot length of garden hose and bucket for priming the pump.

5. Place the pump and motor assembly on a rubber mat. Also, provide a rubber mat upon which personnel who may come in contact with the pump stand. It should not, normally, be necessary for personnel to touch the pump while it is operating. But in the event that there is some reason to do this, the operator should ensure that he is standing on the rubber mat provided and that he uses only one hand for making adjustments (one hand in pocket). Do not allow water to accumulate around the pump or on the surrounding deck. Ensure that the motor shut-down switch is easily accessible (elevated but close to the test apparatus) and safe from electric shock (water-resistant and well-grounded). When aboard ship before energizing pump circuit, have either the ship's or shipyard electrical hazard safety team approve the installation.

6. Assemble test apparatus with bag filter in filter housing. Use see-through hoses for suction side and for section connecting pump to test apparatus. (This will allow for easy detection of air leakage on suction side of pump).

7. Check pump operation. Start pump and initiate pump priming using water from garden hose; then begin drawing water from bucket. Verify proper operation by ensuring that there are no air or water leaks. Presence of air bubbles may substantially reduce capacity of pump. <u>If someone should come into contact with a live electrical circuit, de-energize that circuit before touching that individual</u>.

8. Carry a small tool bag. Do not leave tools unattended or scattered on site. Take all tools with you when leaving the test site.

9. Have an ice chest with sufficient ice available for storing water samples until they can be delivered to the testing laboratory for analysis.

10. Assemble and label water sample bottles.

Test Operations

1. One operator must remain with test equipment at all times while the pump is running. This is to ensure proper operation of test system and to prevent hazard to personnel or damage to equipment in the event of a malfunction.

2. Allow the hydroblasting process to proceed for an hour or so before starting the recycling test. This will ensure that a steady-state condition has been reached.

3. When sufficient wastewater is available, prime the pump and initiate water flow through test equipment. Set flow rate at 8 - 10 GPM or just slightly less than the average rate of generation of hydroblast effluent. Measure flow rate with stop watch and GPM integrating flow meter. Maintain constant flow rate by adjusting the control valve setting for as long as possible.

4. When test is underway, a set of three bottles are needed to collect wastewater samples at six sample ports. Two bottles with a few drops of concentrated nitric acid are for preservation of oil and grease or metals respectively. The third bottle without nitric acid is for the analysis of pH, total solids, nitrite, and nitrate. The six sample ports are:

a. Potable (pier) water.

b. Pier water with nitrite added before entering boiler.

c. Hydroblast wastewater before entering settling tank.

d. Hydroblasting wastewater after leaving settling tank and before entering the first filter.

e. Hydroblasting wastewater between the first and second filters.

f. Hydroblasting wastewater after the second filter.

5. Observe turbidity of wastewater. (Turbidity refers to the degree of particulate suspension within the wastewater). Highly turbid wastewater will quickly cause filter obstruction with particulate matter (see Step 7 below).

6. Monitor performance of test apparatus.

a. Measure and record flow rate every 30 minutes. A lower-than-expected flow, such as 10 GPM, may result from either: (1) loss of pump suction, or (2) increasing pressure drop across the filter. To correct the former, ensure that adequate pump suction is being maintained (i.e., eliminate air leaks on the suction side of the pump). To correct the latter change the filter according to step 7 below.

b. Measure and record pressure differential every 30 minutes.

c. Measure and record pressures every 30 minutes.

d. Ensure adequate supply of wastewater. If wastewater level is reduced to the point that pump suction may be lost, shut filter inlet valve and shut pump off to avoid damage to pump's water-cooled bearings.

7. Monitor the differential pressure across the filter. An increase (at constant flow-rate) indicates the accumulation of solids within the filter. (The rate-of-change of this differential pressure will vary with wastewater turbidity).

a. If the solids in the filter accumulate at a high rate and the flow rate decreases to 5 GPM within 2 hours, obtain a sample before and a sample after filter changes and switch to a clear set of filters. These are single bottle samples with no acid. Replace the used filters with clean ones. Store these used filters containing the solid particulates in a zip-lock bag. The samples will be analyzed for both quantity of solids and for particle size distribution.

b. If the solids in the filter accumulate slowly, continue the test until 8 hours of pumping time have elapsed or until a total of 5000 gallons have been processed.

8. On completion of the recycling test in conjunction with one shift of hydroblast washing of ship boiler tubes (usually 10-12 hours), thoroughly wash skin.

9. Disassemble test equipment. Transfer to Naval Shipyard or transport back to NCEL. Deliver water sample bottles to the shipyard's chemical laboratory and collected solid residues to NCEL for analyses.

TASK HAZARD ANALYSIS

Expected Personnel Hazards

The field test personnel will be working on the pier or aboard a ship in a confined space and in the presence of ship's working personnel. Thus, the test personnel may have to contend with low overhead clearances, noise, and protruding pipes and cables in addition to the other hazards normally associated with ship's repair work in progress. Of special concern will be the hazard of electrical shock due to the presence of water.

Personnel Safety Precautions

Personnel operating the test apparatus are to follow the safety procedures outlined below:

1. Hard hats, safety glasses, and safety shoes are required for operations pierside or aboard ship under repair.

2. Ear plugs and safety goggles will be available. Use of ear plugs is discretionary

3. Some of the sample bottles will have a small quantity of sulfuric or nitric acid to preserve the chemical species in the wastewater. Neoprene gloves and safety goggles must be worn when handling these bottles. (The bottles may leak so that there may be traces of acid on the outside of the bottle). If acid should get on the skin, immediately flush with water for several minutes and report to the dispensary. Contact of acid with skin is indicated by a stinging sensation and a yellowing of the skin. Acid in the eyes is very serious. Copious flushing of the eyes with water is required, followed by the immediate attention of a doctor.

4. Isolate the pump and motor assembly from the ship's deck by placing it on a rubber mat. Do not allow water to accumulate around the pump or on the surrounding deck. Ensure that the motor shut-down switch is easily accessible and safe from electric shock.

5. Do not allow power cords to lie on the ship's deck or the ground because of the potential presence of water. If it is on pier, use 2 x 4's or similar dry wood where/if power cord suspension is impractical.

6. Working quarters may be limited and possibly crowded. Be courteous and cooperative.

7. Thoroughly wash skin after 8 hours of exposure to sodium nitrite solution.

8. Do not work in a situation or perform tasks for which you feel the hazards have not been adequately defined or for which adequate steps in safety have not been taken. Bring unsafe conditions to the attention of the project leader, your supervisor, or as appropriate, ship or shipyard personnel for correction.

9. In an emergency situation, all personnel shall take appropriate action. In a nonemergency situation, the on-site supervisor will determine the appropriate course of action. He shall then report injury to the nearest Navy dispensary and notify all division directors concerned. The on site supervisor shall be responsible for generating all safety related documents.

EMERGENCY RESPONSES

Emergency Medical - Electric shock ______________________

- Acid burns ______________________

- Eye wash ______________________

- First Aid Kit ______________________

Dispensary ______________________________________

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Fire ____

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